Cumulative Effect Of Radiated Emissions From Metallic Data Distribution Systems On Radio Based Services

For
Radiocommunications Agency

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Issue D

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ABBREVIATIONS

ADSL	Asynchronous Digital Subscriber Line
AM	Amplitude Modulation
ATU-C	ADSL Terminal Unit - Central office
ATU-R	ADSL Terminal Unit - Remote
COFDM	Coded Orthogonal Frequency Division Multiplex
DMT	Discrete Multi-Tone
DSLAM	Digital Subscriber Line Access Module
HF	High Frequency (3MHz to 30MHz)
ITU	International Telecommunications Union
LT	Line Termination
MDF	Main Distribution Frame
MF	Medium Frequency (30kHz to 3MHz)
NEC	Numerical Electromagnetics Code
NT	Network Termination
ONU	Optical Network Unit
PLT	Power Line Transmission
POTS	Plain Old Telephone System
PSD	Power Spectral Density
UTP	Unscreened Twisted Pair
VDSL	Very high bit rate Digital Subscriber Line
xDSL	x Digital Subscriber Line (Generic term to describe all DSL technologies)

1 EXECUTIVE SUMMARY

Recent developments in broadband data access methods over existing telephone or mains wiring will cause unintentional RF emissions which may adversely affect the established radio noise floor. This report considers the effects due to cumulative propagation of many such sources on the established radio noise floor. It does not consider possible interference due to near field effects. The propagation mechanisms considered are groundwave and skywave. Figure 1.1 shows the technologies, propagation methods and frequencies that have been considered.

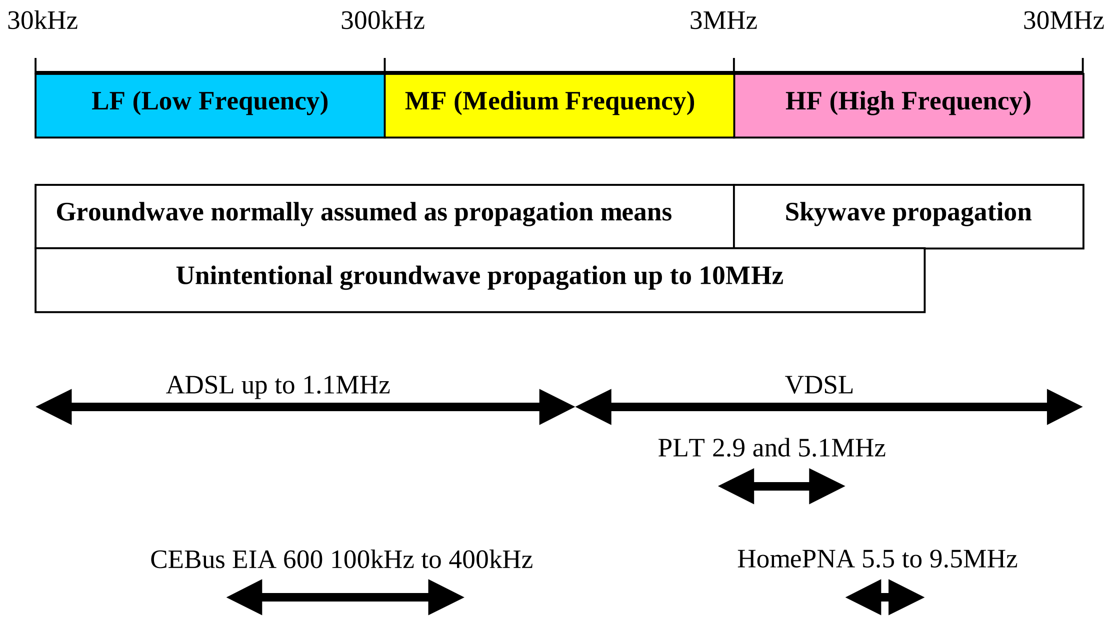


Figure 1.1: Figure showing frequency bands, propagation methods and major technologies considered in this report

1.1 Groundwave cumulative emissions

Various combinations of cumulative sources are considered, some possible worst case figures are drawn from the report and tabulated in Table 1.1[1], similarly Table 1.2 tabulates worst case skywave cumulative propagation. From comparison of Table 1.1 with Table 1.2 it can be seen that groundwave propagation is the mechanism that is likely to lead to the largest increases in the established radio noise floor.

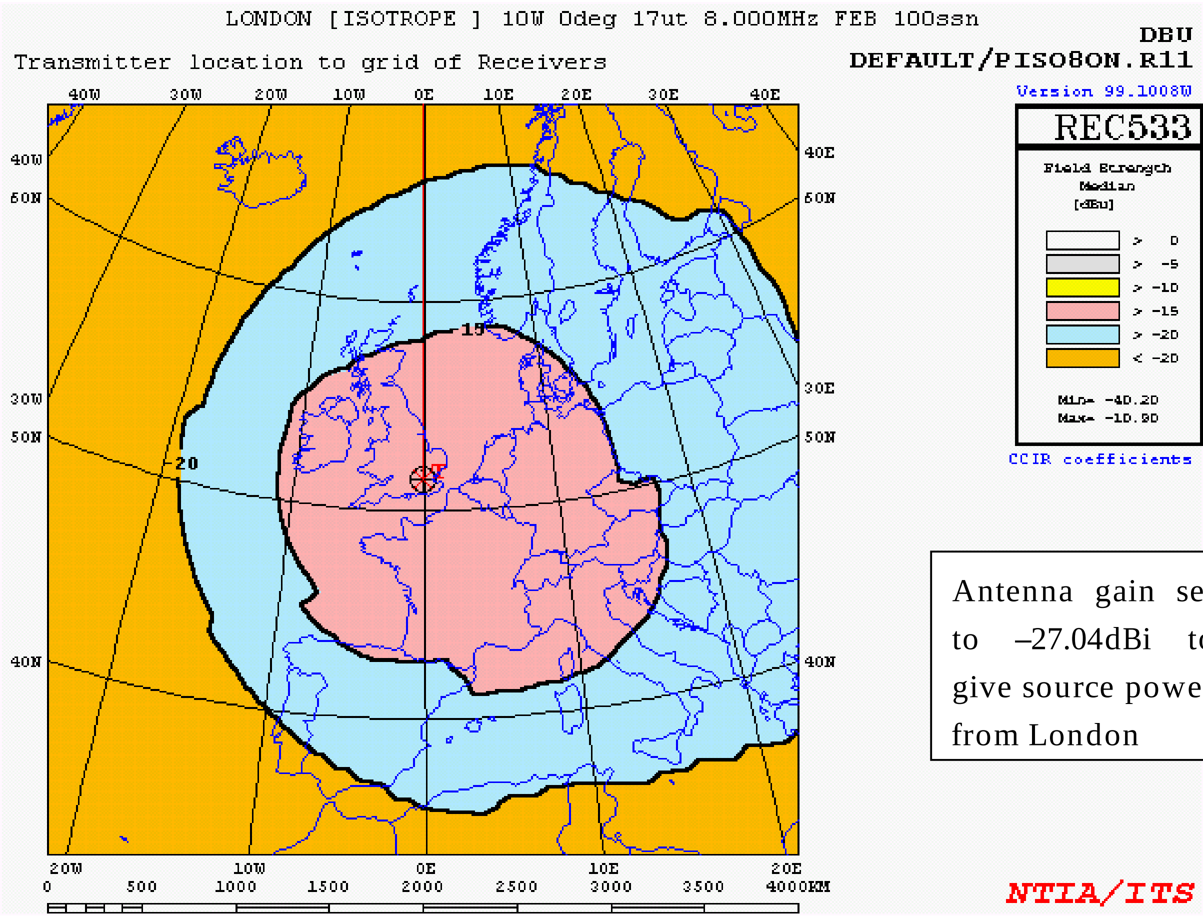
[1] The absolute levels in the table are based on unvalidated numerical models.

Technology	Frequency (MHz)	Established ITU noise floor in 10kHz bandwidth, rural location, summer (dBµV/m)	Field in 10kHz bandwidth at 1km from city (dBµV/m)	Field in 10kHz bandwidth at 10km from city (dBµV/m)
PLT	3	8.1	59.2	14.2
ADSL	1	10.76	26.15	1.15
VDSL	6	5.92	28.74	-16.26

Table 1.1: Summary table of possible worst case field due to cumulative groundwave propagation of various technologies compared to the ITU noise floor

1.2 Skywave cumulative emissions

The threat posed by skywave propagation is very different to that posed by groundwave propagation. The study has found that a good representation of a large city is an isotropic antenna with a cumulative power source. For the maximum increase in the localised radio noise floor due to skywave propagation the noise frequency must be below the critical frequency. The critical frequency is the highest frequency that will be reflected back down to earth for a wave beamed at the ionosphere with normal incidence. If the noise frequency is above the critical frequency then the radiation is lost to space and no localised increase in field will be seen. Table 1.2 presents a summary of possible contributions to radio noise floor from cumulative skywave propagation for all of the broadband data access technologies considered in this study. Figure 1.2 shows the situation for cumulative VDSL at 8MHz which is just below the critical frequency. The Figure shows that the coverage area is much greater than for the groundwave case suggesting that any increase in the radio noise floor due to skywave propagation would be Europe wide and not localised to the region surrounding a town or city as is the case for groundwave propagation.



Antenna gain set to –27.04dBi to give source power from London

Figure 1.2: Coverage due to cumulative VDSL from London in dBµV/m (assumptions, 25% market penetration in full use and 20dB of cable balance)

The field values for an individual city are much lower than for groundwave propagation using similar assumptions. However because of the large coverage of any one city if the contributions from major cities in the UK and Germany are power summed then a larger value is reached. The situation for the various technologies is summarised in Table 1.2. It will be seen from the table that the only technology that is likely to significantly increase the established radio noise floor due to cumulative skywave propagation is PLT. This implies that skywave propagation of the other technologies considered is not expected to affect MF/HF radio services.

Technology and assumed penetration (%)	**Assumed single source antenna factor (dBi)**	**Cumulative source**	**Frequency bands (MHz)**	**Field in 10kHz bandwidth due to technology deployment (dBµV/m)**	**Established ITU noise floor in 10kHz bandwidth, rural location, summer (dBµV/m)**
PLT - 100%	-15	All UK and Ruhr	2.2 to 3.5	7.5	8.1
			4.2 to 5.8	7.5	6.44
VDSL - 25%	-25	All UK and Ruhr	8(worst case skywave frequency)	-6	5.22
HomeLAN mains cable - 5%	-33	Greater London	3.3	-8	8.1
	-28.2		8.2	-13	5.22

Table 1.2: Summary of possible contributions to radio noise floor from cumulative Skywave propagation

1.3 Spectrum management

User	**Frequencies and comments**
AM and HF Broadcasting	148.5 kHz - 283.5 kHz, 505 kHz - 1606.5 kHz, 5.9 MHz - 6.2 MHz, 7.1 MHz - 7.35 MHz, 9.4 MHz - 9.9 MHz. Significant future developments in this band include the launch of digital AM radio by the Digital Radio Mondiale (DRM) consortium probably during 2001.
Amateur Service	72 kHz - 84 kHz, 130 kHz - 148.5 kHz, 1810 kHz - 2000 kHz, 3500 kHz - 3800 kHz, 7000 kHz - 7100 kHz (including satellite service).
Aeronautical radionavigation (Non-directional beacons)	255 kHz - 495 kHz, 505 kHz - 526.5 kHz. Aeronautical non-directional beacons (NDBs) are currently the subject of continued development.
Aeronautical mobile (including HF communications)	2194 kHz - 2498 kHz, 2502 kHz - 2625 kHz, 2650 kHz - 3230 kHz, 3400 kHz - 3500 kHz, 3800 kHz - 3950 kHz, 4438 kHz - 4850 kHz, 5450 kHz - 5730 kHz, 6525 kHz - 6765 kHz, 8815 kHz - 9040 kHz. Intense interest is concentrating into the development of digital aeronautical HF communications in the form of data links. The new services are addressing air traffic control (ATC) issues as well as voice and data communications. A substantial increase in the number of users and ATC coverage expansion to include Polar Regions is expected.

Table 1.3: Current spectral allocation in the United Kingdom within the radiatively important xDSL frequency band (100 kHz - 10 MHz)

Digital MF broadcasting services are expected to become operational from the year 2001. They will use substantially less power to cover equal areas than older technology. Existing analogue services will continue to be in active service for a period of about 10 to 15 years, but will eventually be phased out by the year 2030.

For existing analogue MF broadcasting services the calculations suggest they are unlikely to be affected by the cumulative xDSL groundwave propagation at distances greater than 3km from the effective emission centre. Nevertheless, at shorter distances and inside customers' properties the xDSL near fields are thought to present a much more important radiative threat to existing and future radio services. In any case, should analogue services be withdrawn and all MF broadcasting be converted to digital format, it would be useful to contain xDSL emissions at a maximum level of 20dB above the currently established radio noise floor. (For the UK lower values of noise floor than those in the ITU-R 372 recommendation could be used.) Such a regulation will guarantee minimal future disruption to digital MF broadcasting. At the same time, by setting the adjacent-channel protection ratio between digital transmissions at the same level (i.e., 20dB over the currently established radio noise floor), very low power solid state transmitters can be used to provide service to large areas. The resultant benefits will include a much quieter electromagnetic environment, substantial fossil fuel savings and reduction of emissions of greenhouse gases.

The effect of xDSL emissions on military communications has not been considered in detail in this report. Nevertheless, our cumulative emission field calculations clearly suggest that military communications will be adversely affected at selected areas. Before however definitive conclusions are drawn, a thorough theoretical study supported by exhaustive experimental evidence should be conducted. The military services likely to be affected concern mainly mobile communications.

1.4 Mitigation techniques

The following are measures which would reduce the possibility of excessive increases in radio noise floor due to deployment of ADSL and VDSL technologies.

- Cables with good balance over the entire frequency range used by xDSL (25 kHz to 30 MHz) should be used to minimise emissions. In addition the balance and matching at interconnection points also needs to be of high quality. This is particularly important for VDSL and the other high frequency xDSL technologies which operate at much higher frequencies than the existing local loop infrastructure was designed to support. Our results suggest that the cumulative emissions from an installation with an overall balance of 50 dB will not have significant impact on radio services. Improving the balance of the system will also reduce the level of noise ingress into the xDSL signal paths and thus increase the achievable data rate.

- The use of splitterless technology is not recommended.
- In the case of VDSL siting the Optical Network Unit (ONU) as close as possible to the end user is recommended.
- Exclusion zones would need to be employed in the vicinity of “sensitive receiving sites” due to potential groundwave propagation interference.

The following are measures which would reduce the possibility of excessive increases in radio noise floor due to deployment of PLT technology.

- The use of mains conditioning units[2] is recommended to minimise the signal levels present on the mains wiring of a house. This however will have no effect on the emissions from other street furniture or buried cables.
- Exclusion zones would need to be employed in the vicinity of “sensitive receiving sites” due to potential groundwave propagation interference. The effectiveness of these would be limited by skywave propagation as the coverage area for cumulative skywave propagation is very large as illustrated in Figure 1.2.

[2] See section 10.2

2 INTRODUCTION

There is a potential threat of Radio Spectrum pollution from wide band digital data distribution systems that operate over either the electricity mains network or the public telephone network. Particularly of concern is the expected high take up of this technology in the domestic environment where high speed data connectivity is the driving force. It is possible that the combined interference from many installations will produce an increase in the established radio noise floor. This would make the reception of radio communications less reliable, particularly in urban areas. This report investigates the possible changes in radio noise floor due to PLT (Power Line Transmission), xDSL (x Digital Subscriber Line) and HomeLAN technologies resulting from Skywave and Groundwave propagation of their cumulative emissions. Spectrum management issues and possible mitigation techniques with respect to these findings are also addressed.

2.1 Overview of technologies

PLT uses unbalanced mains cabling as a transmission medium and is therefore a potential source of unintentional radio frequency broadcasting. There is interest in the technology both in the UK and Germany with lobbying for provision in standards to allow significant emissions centred around the frequencies of 3 and 5MHz with 1.5MHz of bandwidth.

xDSL (x Digital Subscriber Line) is a group of technologies backed by the telephone companies to provide high bandwidth digital services to the home and small business using the existing copper telephone cabling. There are several forms of xDSL, each aimed at specific market sectors. ADSL (Asymmetric Digital Subscriber Line) has undergone trials by both BT and Kingston Telecom in the UK. If the trials are successful it is expected that widespread commercial deployment of the technology will occur from March 2000. ADSL allows the possibility of data transmission, using bandwidths up to 8Mbps, to the home over existing telephone lines. The transmission frequencies for ADSL are between 25kHz and 1.1MHz. VDSL (Very High Bit-rate Digital Subscriber Line) is also under development where data rates up to 50Mbps are proposed. VDSL may use frequencies up to 30MHz although the final standard is still being developed.

HomeLAN technology uses existing transmission media in the house for digital data transmission so that no new wiring need be installed. With this in mind there are three possible media that a HomeLAN system can use, namely: the existing mains wiring of the house, the existing telephone wiring in the house, or wireless transmission. In the UK wireless HomeLAN kits and kits which use the telephone cabling as the media are readily available in computer shops. Present systems allow data speeds up to 1Mbps but, 10Mbps systems are about to become available with 100Mbps systems being developed.

3 INVESTIGATION OF PROPAGATION OF CUMULATIVE PLT EMISSIONS

3.1 Review of previous work relating to propagation of PLT radiated emissions

The starting point for this project was the Radiocommunications Agency report "Final report on a study to investigate PLT radiation"[i]. The report presented measured and predicted radiated emissions from representative mains networks when injected with RF signals up to 30MHz. Modelled field patterns of radiation from house wiring were also presented. It was anticipated that these field patterns and levels would provide the starting point for the levels that would need to be propagated in this study.

Two papers were found that presented models for the propagation of radiation from PLT systems. The first one by Widmer[ii] treats the skywave propagation using propriety HF propagation software. Following his treatment he concludes that providing the PSD (Power Spectral Density) of the PLT system is no greater than -40dBm/Hz, there should be no disturbance of HF radio services with respect to ionospheric skywave propagation. The second paper by Stott[iii] covers both groundwave and skywave propagation. He uses no computer programs and presents all formulae used in his analysis. He concludes that groundwave propagation gives a higher threat field than skywave propagation and provides tables of exclusion distances so that 'sensitive receiving sites' may be protected from the groundwave propagation of PLT radiation.

PLT technologies are proprietary and as such, there is at present no standard describing transmission frequencies, modulation, coding etc. although, it is understood that standards bodies are beginning to formulate specifications. The powerline companies are proposing two frequency 'slots' in which they wish to be protected from regulatory action against themselves. Both the Radiocommunications Agency in the UK and their German equivalent, Reg TP, are proposing near field emissions standards with respect to mains cabling. The standards[iv,v] run from 10kHz to 30MHz. In the UK it is intended that in the case of reported interference MPT 1570 would be used to adjudicate under section 10 of the Wireless Telegraphy Act. The power companies in both the UK and Germany are lobbying for "exemption chimneys" in these limits[vi]. These chimneys are at 2.2 to 3.5MHz and 4.2 to 5.8MHz.

3.2 Groundwave propagation of cumulative PLT emissions

Stott[iii] has given a thorough treatment of this topic. His reasoning is not reproduced here although it is drawn on for the skywave treatment given in the next section. To summarise his results the table of exclusion distances he deduced for 3MHz are given in Table 3.1.

Exclusion distance (km)	Equivalent field strength (dBμV/m in 10kHz)
10	14.2
20	8.25
30	3.25
50	-2.4
100	-10.2
200	-25.8

Table 3.1: Stotts wet ground exclusion zones for PLT, representative of the UK

3.3 Skywave propagation of cumulative PLT emissions

3.3.1 Cumulative antenna gain patterns

The cumulative antenna gain pattern formed by a city or large urban area is crucial to how the power radiated from the city will be propagated to the far distance by either skywave or groundwave means. It is considered likely that a large number of radiators, because of their variety and random orientation, would look like an isotropic antenna when viewed at some distance. However, it is known that some of the component radiators examined in the course of this study have a reduced gain at higher and lower angles of elevation. (Moving along the ground is 0° of elevation, moving up orthogonally from the ground is 90° elevation.) Hemispherical antenna patterns of a house and a short street were derived using the Numerical Electromagnetics Code (NEC). To help clarify whether the isotropic assumption is valid, a computer program was developed to allow the cumulative addition of these antenna patterns. The program was given as input a number of house and short street antenna patterns which were then summed over a greater hemisphere which enclosed all the patterns. Each source pattern was located in the enclosing hemisphere by an x, y coordinate relative to the centre. In addition each source pattern also had an azimuth associated with it so that the pattern orientation was not fixed.

Initial experiments with the program quickly showed that the observation distance (the radius of the enclosing hemisphere) was important. It was found that making the hemisphere large compared to the distance **a**, shown in Figure 3.1 preserved the antenna pattern whereas making its radius comparable to **a** caused the sum of the sources to look isotropic. This observation posed a question. What is a suitable radius for the enclosing hemisphere? The F2 layer in the ionosphere is the most important region for causing reflection of HF back to the earth. Section 3.3.3 finds that the radiation from PLT will be propagated most strongly on a February evening. At 6 o'clock on a February evening the height of the F2 layer is approximately 300km above the earth. Its height varies depending on time of day and time of year, however it is normally between 250 and 350km. Therefore 300km was chosen as the radius for the enclosing hemisphere. The situation is sketched in Figure 3.2.

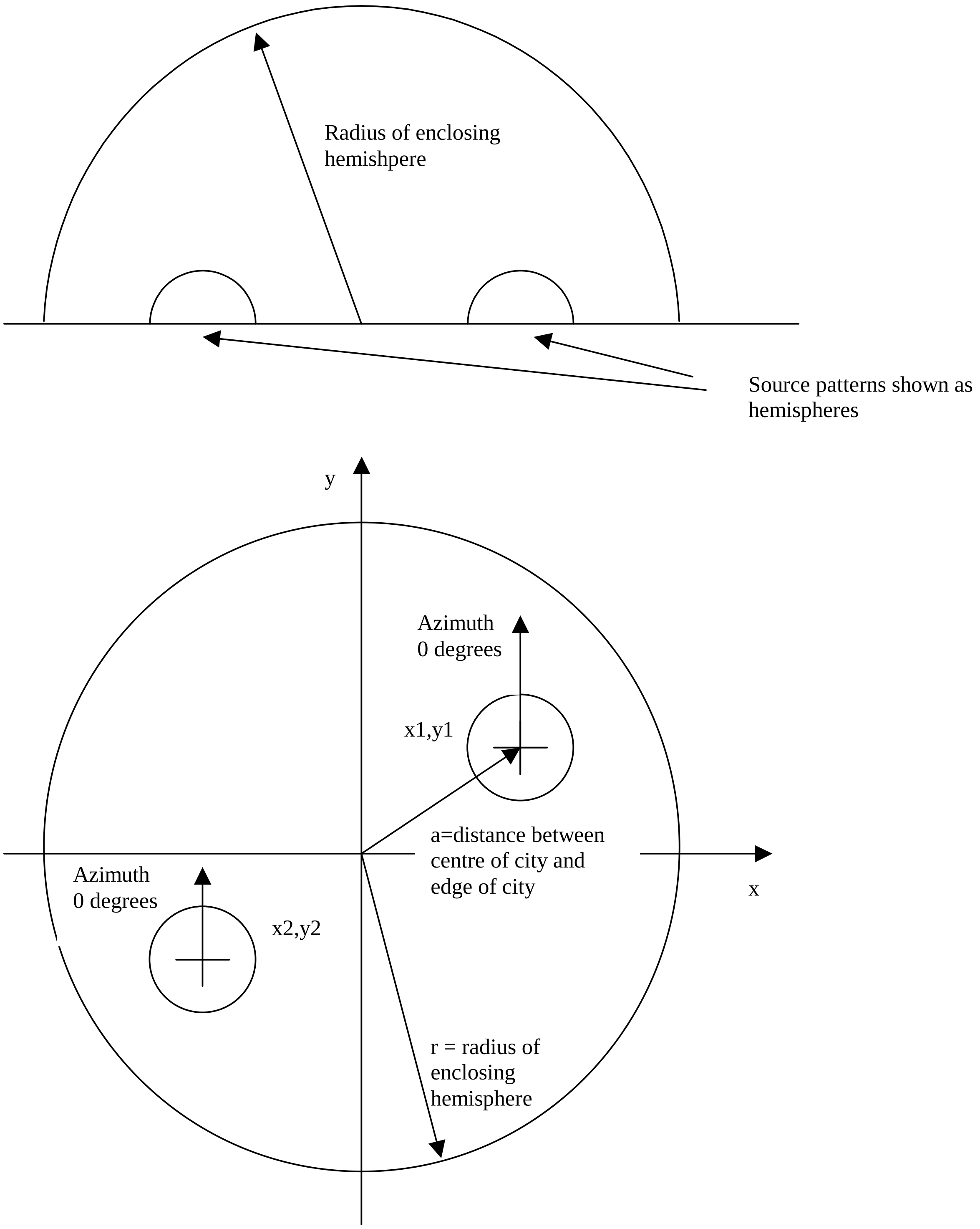


Figure 3.1: Illustration of method of addition of power patterns

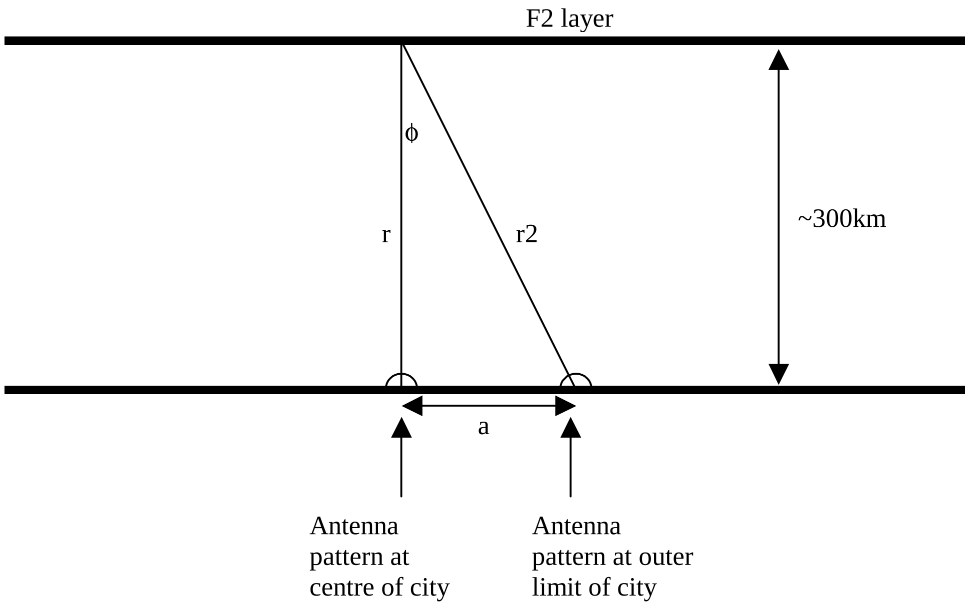


Figure 3.2: Geometry of a city as a cumulative antenna with respect to the F2 layer

With reference to Figure 3.2 it was assumed that the antenna patterns at the centre and edge of the city were identical with the same azimuth. Then for small ϕ the contribution from the two patterns at F2 will be identical. In other words if the F2 layer is high enough then the power pattern from the city as a whole will be preserved. Substituting numbers into the trigonometry will indicate whether the power pattern from a large city can be expected to be preserved.

$$\phi = \tan^{-1}\frac{a}{r}$$

Power patterns from antennas are usually presented on polar plots measured in degrees although if measurements of antenna performance are being carried out ten degree steps usually gives a good indication of the power pattern of the antenna. Therefore if $\phi<10°$, the power pattern would be expected to be preserved. Substituting $\phi=10°$ into the above equation gives a maximum city radius of 52.8km. The radius of greater London is approximately 28km, hence the power pattern is expected to be preserved.

3.3.2 Cumulative antenna pattern applied to PLT analysis

The building block used for the PLT antenna pattern was a short street consisting of twelve houses as shown in Figure 3.3. The wire loops representing housing ring mains are regarded as the main radiating element. The radiation from the short street was derived using NEC with a lossy ground.

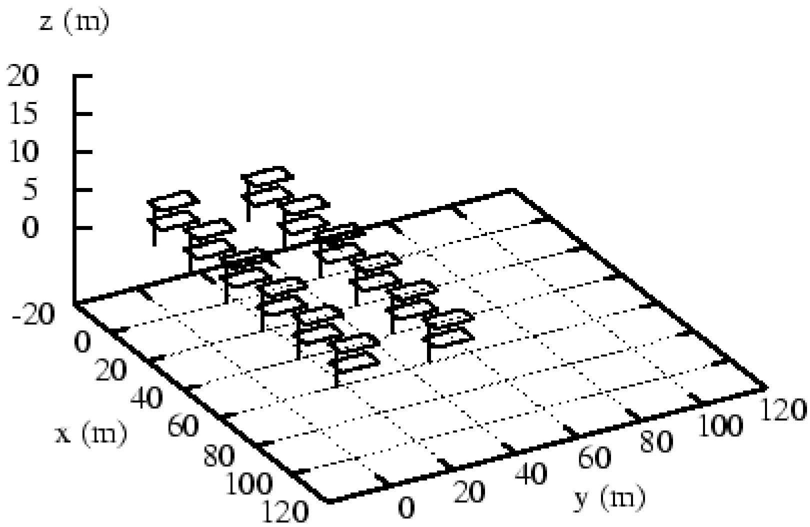
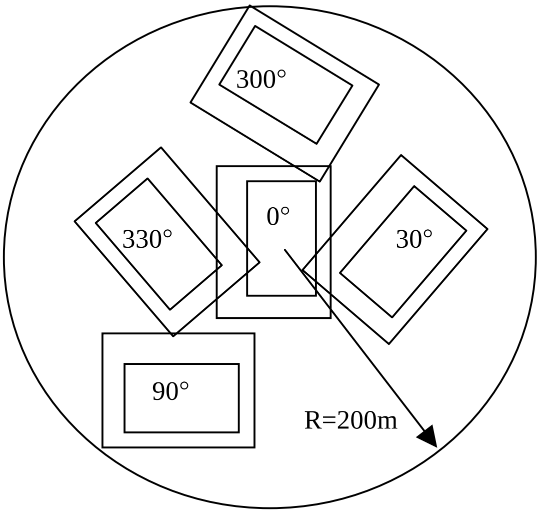


Figure 3.3: Illustration of the NEC model for a short street with lossy ground

Inspection of the gain profiles shown in Appendix 1 showed that the short street at 2.9MHz had a close fit to an isotropic antenna. At 5.1MHz the gain at 90° was noticeably flattened and it was decided to test the thesis of section 3.3.1 by summing the 5.1MHz pattern over an area the size of London and a hemisphere of radius 300km.

3.3.2.1 Summing of short street antenna pattern to make a cumulative PLT antenna pattern for London

The short street shown in Figure 3.3 covers an area of approximately 3200m^2, however, greater London covers an area of approximately 2500km^2. The main objectives when using the pattern to build up a large area were to make the position of the streets with respect to azimuth as random as possible and also to obtain a reasonably even distribution of patterns over the whole 2500km^2 area.



Values in degrees indicate off azimuth angle in degrees of street

Figure 3.4: Five street geometry used as building block to create London geometry

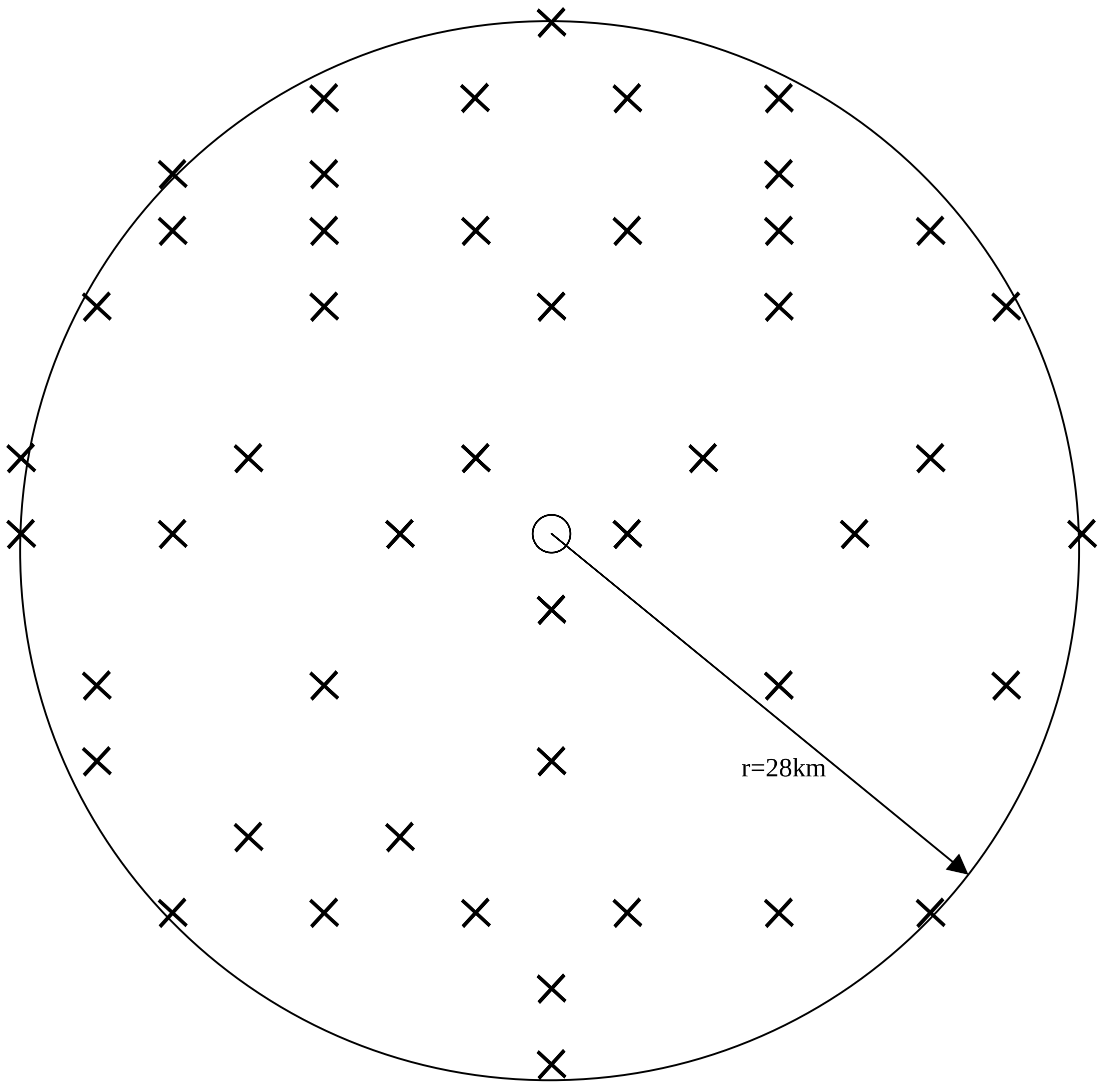


Figure 3.5: London geometry, showing locations of forty nine, five street geometries summed over hemisphere of 300km (the distance to the F2 layer)

To facilitate this an intermediate level summation of five streets was performed having the geometry as shown in Figure 3.4. The five street geometry was then summed over a circular area to represent London as shown in Figure 3.5.

3.3.2.2 Results of London cumulative geometry summation

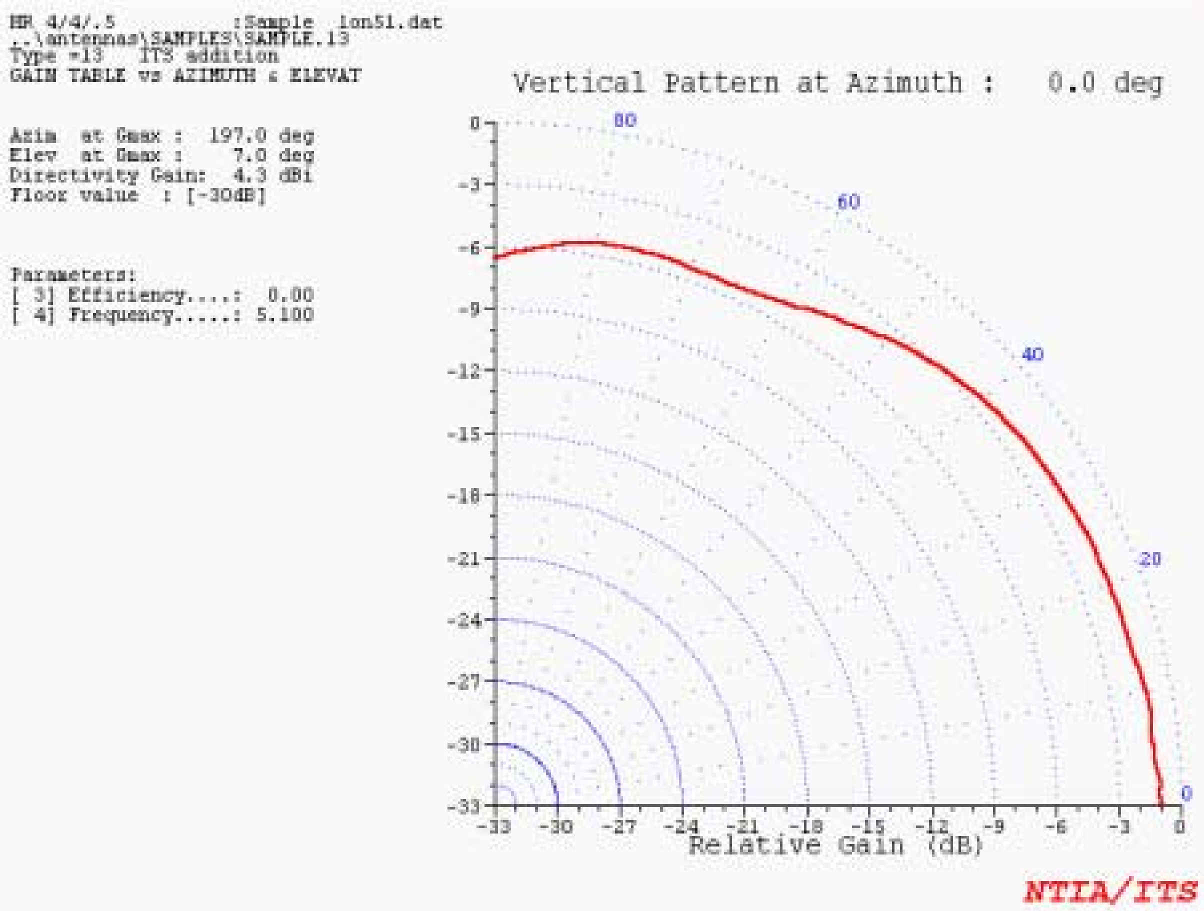
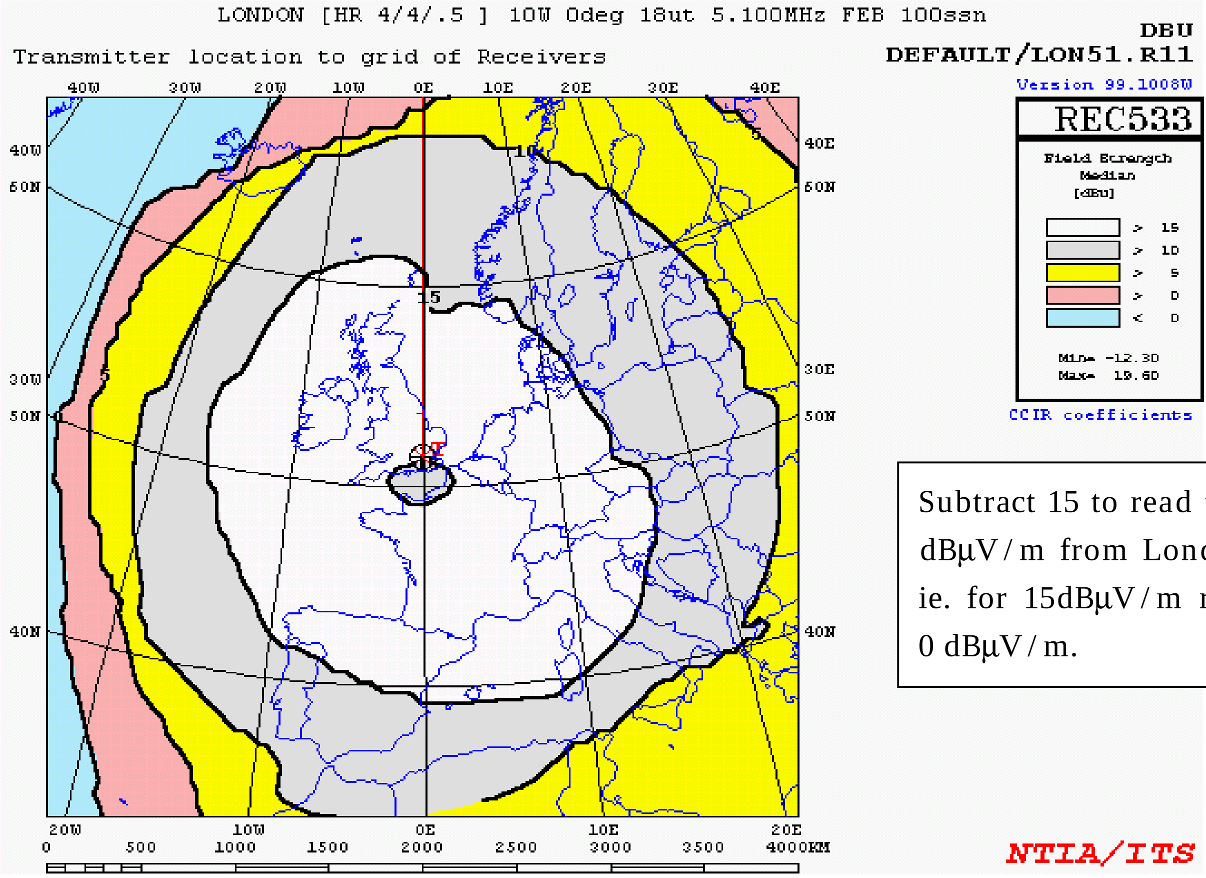
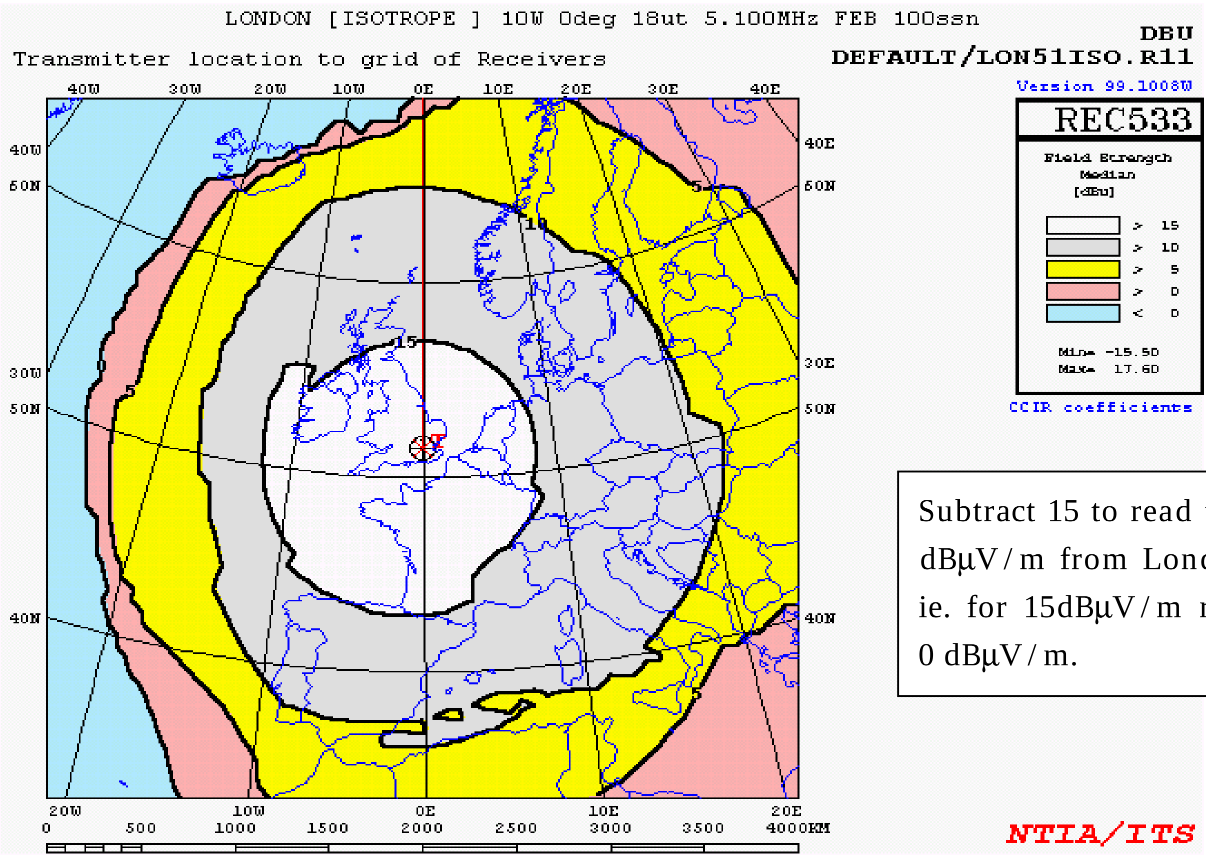


Figure 3.6: Cumulative PLT antenna pattern for London

Figure 3.6 shows a cross section at 0° azimuth of the pattern created by the summation. As expected from the discussion of geometry in section 3.3.1 the 6dB dip at 90° elevation is still apparent after the summation of many source patterns. Further sections through the antenna pattern are given in Appendix 1, these are identical as would be expected. The resultant pattern still looks essentially isotropic in nature however, and this antenna pattern was expected to have no appreciable effect on the predictions given using a pure isotropic antenna. To verify this a skywave coverage plot using the above pattern is presented in Figure 3.7 it is compared with a coverage plot using an isotropic antenna.



Subtract 15 to read true dBµV/m from London. ie. for 15dBµV/m read 0 dBµV/m.



Subtract 15 to read true dBµV/m from London. ie. for 15dBµV/m read 0 dBµV/m.

Figure 3.7: Comparison of coverage pattern with London cumulative antenna (top) against isotropic antenna (bottom)

The skywave coverage plots were produced using the ITS (Institute for Telecommunications Sciences) HF propagation software[vii]. The package caters for area coverage or point to point problems. It provides a number of different propagation models with a common user interface. The model used throughout the skywave propagation work in this report was the ITU recommendation 533. The ITS Rec533 program is the point to point implementation and Recarea is the area coverage program.

It will be seen from Figure 3.7 that the coverage given by the summed pattern is very similar to that given by an isotropic antenna. It seems reasonable to conclude therefore that for PLT, a good representation of the cumulative antenna pattern for a city is an isotropic one.

3.3.3 HF propagation of PLT radiation representing cities as isotropic antennas

From the previous sections it can be concluded that representing a city as an isotropic antenna is normally a good approximation. Having decided the antenna type, an estimate of the likely input power was required. From Stott[iii] all premises connected to one electricity sub-station form a group or cell. Only one modem out of the sub-station or premises transmits at a time sharing the capacity of approximately 1Mbit/s in Time Division Multiplex (TDM). The maximum density of instantaneously operating systems is therefore the same as the density of sub-stations. Stott[iii] gives the urban area covered by one sub-station to be a circle of diameter 600m. This works out to be one sub-station every 0.28km^2 or 3.57cells/km^2. Widmer uses a value of 0.35cells/km^2 but this appears to be averaged over a whole country. The following details the assumptions used.

<u>Power in 10kHz bandwidth</u>

The proposed power level is –40dBm/Hz. In 10kHz this gives 1mW.

<u>Urban area to treat</u>

The largest urban area in the UK is that within the M25 which is approximately 2500 km^2. At least 80% of this area is built on. There is additional built up area outside the M25 . Using the area of 2500km^2 seems reasonable.

<u>Number of sub-stations within M25</u>

Using Stott cell size = 2500x3.57 =8925

<u>Total power available for radiation</u>

total number of subs. x 1mW = 8.925W ~ 40dBm

Antenna efficiency

What portion of the input RF is radiated? Stott quotes an antenna efficiency of –17dBd to –27dBd (dBd is with respect to dipole). A dipole has a gain of 2.15dBi. Taking the worst case gave an antenna gain of –15dBi.

Worst case radiated power from London

Total power available for radiation + gain = 40 –15 = 25dBm

The lowest transmitter power allowed by the ITS propagation software is 1W (30dBm) which caused a problem as nearly all the sources considered were less than 1W. *The power for all cases considered in this section was therefore set at 10W (40dBm) and the predicted field strength suitably renormalised. For the case of London, for example, all output results were reduced by 15dB.*

HF propagation levels vary greatly depending on the time of day and the month of the year. Solar activity is also important, for the study described an average level of solar activity has been selected. Propagation of the frequencies involved was found to be greatest in February. This was determined by using the ITS point to point propagation program for ten months and picking the month with the highest levels of propagation. Appendix 2 gives the plots for the various months. The next variable to consider was the time of day. Appendix 3 gives the coverage from London for both 2.9MHz and 5.1MHz at 06, 12, 18 and 24 hours during the day. It was found that the coverage was highest at 18.00hrs.

Similar calculations to the above were then performed for Manchester, Birmingham and the Ruhr industrial area of Germany. Plots for these calculations are given in Appendix 4.

3.3.4 Summation of coverage from major UK cities and Ruhr area of Germany

Study of the coverage plots in the Appendices makes it apparent that: at 6 o'clock in the evening, in February, all the sources considered, gave even coverage over the UK with very little decay in field strength over the entire area. It was therefore assumed that all sources have no significant decay over the UK, this made summing the total contribution from each of the major UK cities relatively straightforward. Table 3.2 shows the case where the electric field from each source was assumed to be no greater than 20dBμV/m derived from the plots in the Appendices. Table 3.3 shows the case where the electric field from each source was assumed to be no greater than 15dBμV/m derived from the plots in the Appendices.

Source city/area	Area (km^2)	No. of sub-stations	Total source power (dBm)	Portion radiated (dBm)	dB down on 10W	dBμV/m over UK	Power (W/m^2) over UK
Ruhr	3507.00	12519.99	40.98	25.98	14.02	5.98	7.9183E-14
London	2500.00	8925	39.51	24.51	15.49	4.51	5.6447E-14
Birmingham	900.00	3213	35.07	20.07	19.93	0.07	2.0321E-14
Manchester	625.00	2231.25	33.49	18.49	21.51	-1.51	1.4112E-14
Glasgow	375.00	1338.75	31.27	16.27	23.73	-3.73	8.467E-15
Liverpool	300.00	1071	30.30	15.30	24.70	-4.70	6.7736E-15
Leeds/ Bradford	275.00	981.75	29.92	14.92	25.08	-5.08	6.2091E-15
Stoke on Trent	218.00	778.26	28.91	13.91	26.09	-6.09	4.9221E-15
Nottingham	187.00	667.59	28.25	13.25	26.75	-6.75	4.2222E-15
Sheffield	180.00	642.6	28.08	13.08	26.92	-6.92	4.0642E-15
Bristol	150.00	535.5	27.29	12.29	27.71	-7.71	3.3868E-15
Edinburgh	120.00	428.4	26.32	11.32	28.68	-8.68	2.7094E-15
Belfast	100.00	357	25.53	10.53	29.47	-9.47	2.2579E-15
Leicester	100.00	357	25.53	10.53	29.47	-9.47	2.2579E-15
Coventry	75.00	267.75	24.28	9.28	30.72	-10.72	1.6934E-15
Cardiff	75.00	267.75	24.28	9.28	30.72	-10.72	1.6934E-15
					Total power (W/m^2)		**2.1872E-13**

Table 3.2: Total power from each source when contribution from each source is assumed to be relative to 20dBμV/m on the plots

Source city/area	Area (km^2)	No. of sub-stations	Total source power (dBm)	Portion radiated (dBm)	dB down on 10W	dBμV/m over UK	Power (W/m^2) over UK
Ruhr	3507.00	12519.99	40.98	25.98	14.02	0.98	2.504E-14
London	2500.00	8925	39.51	24.51	15.49	-0.49	1.785E-14
Birmingham	900.00	3213	35.07	20.07	19.93	-4.93	6.426E-15
Manchester	625.00	2231.25	33.49	18.49	21.51	-6.51	4.4625E-15
Glasgow	375.00	1338.75	31.27	16.27	23.73	-8.73	2.6775E-15
Liverpool	300.00	1071	30.30	15.30	24.70	-9.70	2.142E-15
Leeds/ Bradford	275.00	981.75	29.92	14.92	25.08	-10.08	1.9635E-15
Stoke on Trent	218.00	778.26	28.91	13.91	26.09	-11.09	1.5565E-15
Nottingham	187.00	667.59	28.25	13.25	26.75	-11.75	1.3352E-15
Sheffield	180.00	642.6	28.08	13.08	26.92	-11.92	1.2852E-15
Bristol	150.00	535.5	27.29	12.29	27.71	-12.71	1.071E-15
Edinburgh	120.00	428.4	26.32	11.32	28.68	-13.68	8.568E-16
Belfast	100.00	357	25.53	10.53	29.47	-14.47	7.14E-16
Leicester	100.00	357	25.53	10.53	29.47	-14.47	7.14E-16
Coventry	75.00	267.75	24.28	9.28	30.72	-15.72	5.355E-16
Cardiff	75.00	267.75	24.28	9.28	30.72	-15.72	5.355E-16
					Total power (W/m^2)		**6.9165E-14**

Table 3.3: Total power from each source when contribution from each source is assumed to be relative to 15dBμV/m on the plots

The total power in each case was calculated to be as seen in a 10kHz bandwidth. Using the value of 15dBμV/m gave a minimum expected power whilst using the value of 20dBμV/m gave a value larger than expected. Using the minimum expected total power gave the value of 5dBμV/m over the UK whereas using the larger than expected value gave 11dBμV/m.

From this analysis the noise voltage into a 10kHz bandwidth, at 18.00 in February, over most of the UK is expected to be between 5dBμV/m and 11dBμV/m. This is the worst case for HF skywave propagation.

The key variable in the calculation is the antenna efficiency of the PLT network, the value used was the worst case quoted by Stott[iii]. The best case he gives is 10dB less efficient. Assuming an average antenna factor between the worst and best case would give a reduction of 5dB on the above values. This should be treated with some caution however as Womersley et al[i] give a worst case value of –11dBd as the antenna efficiency which is 6dB more efficient than the worst case of Stott.

4 MEASUREMENT OF EMISSIONS FROM UNSHIELDED TWISTED PAIR

4.1 Background

xDSL equipment was not available, to perform emission measurements on, during the course of this study. Therefore, in order to obtain quantitative information on the electrical balance of the local loop distribution system, a number of measurements were made on generic cable geometries representative of segments of the network. The measurements were made at the Radiocommunications Agency's Whyteleafe Laboratory.

4.2 Test Configurations

Measurements were made on both horizontal and vertical runs of unshielded twisted pair (UTP) cable; Figure 4.1 shows the general experimental layout used in both cases. The cable used was a standard telecommunications (POTS) Number 10 drop wire which consists of a bundle of two UTP's and steel strengthening wires. Only one of the UTP's from the bundle was excited in the experiments. One end of this pair was terminated with a 100Ω load while the other end was fed, via a coaxial cable, with a continuous wave signal from a signal generator and amplifier. In order to minimise radiation from the feed mechanism a microwave quality superscreened coaxial cable was employed.

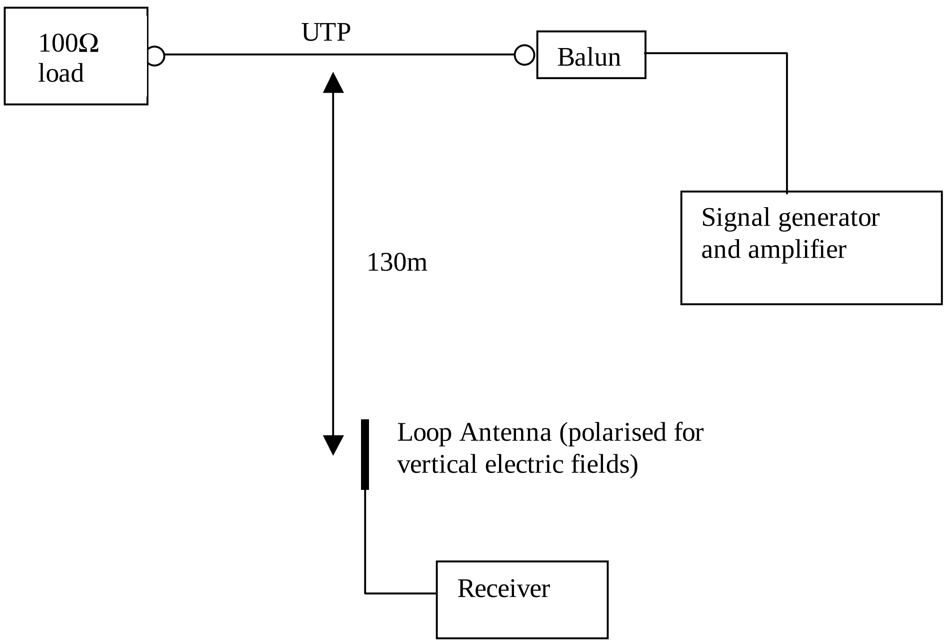


Figure 4.1: General experimental layout for all the tests

A high quality wideband balun (North Hills[viii,ix]) was used to interface the coaxial cable and the UTP so that the balance of the feed point was well controlled. This was expected to be representative of the best balance which can be achieved in the system and is denoted the "balanced" case in this section. In order to place bounds on the overall balance of a real system measurements were also made with one wire of the UTP connected to the case of the balun. The balun case has a 360 degree electrical phase relation to the outer conductor of the coaxial cable. This is denoted the "unbalanced" case and may be more representative of the typical balance achieved in practice. For example, Figure 4.2 illustrates the connection of UTP at the exchange end of the line showing an earth connection at one side of the capacitor which may unbalance the system.

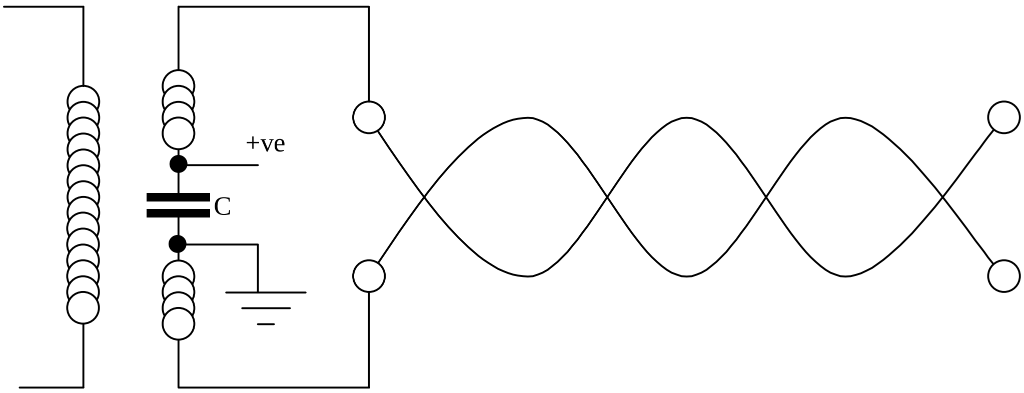


Figure 4.2: Connection of UTP at the exchange end of the local loop

The strength of the magnetic field radiated by the structure was measured at a range of 130m using a very sensitive tuneable loop antenna specially designed for the RA. The antenna was polarised to receive vertically polarised electric fields. Horizontally polarised fields were not considered since they are rapidly attenuated by the ground and therefore do not contribute significantly to cumulative ground wave propagation. Field strengths were measured at frequencies in the range 0.1kHz to 15MHz using a drive power of 1W (30dBm). The frequencies were chosen to give good coverage of the xDSL bands and adjusted to avoid areas of the spectrum where there were high ambient fields. In some cases the power was increased to 40dBm to improve the sensitivity of the measurements and the fields suitably renormalised.

Figure 4.3 shows the details of the horizontal cable test. A 40m length of UTP was suspended 6m above ground using plastic poles. The cable was fed from the top of one pole and terminated at the top of the other pole. For the vertical cable tests (see Figure 4.4) a 3m and a 6m length of UTP was hung down the side of a plastic pole. The cable was fed at the bottom and terminated at the top.

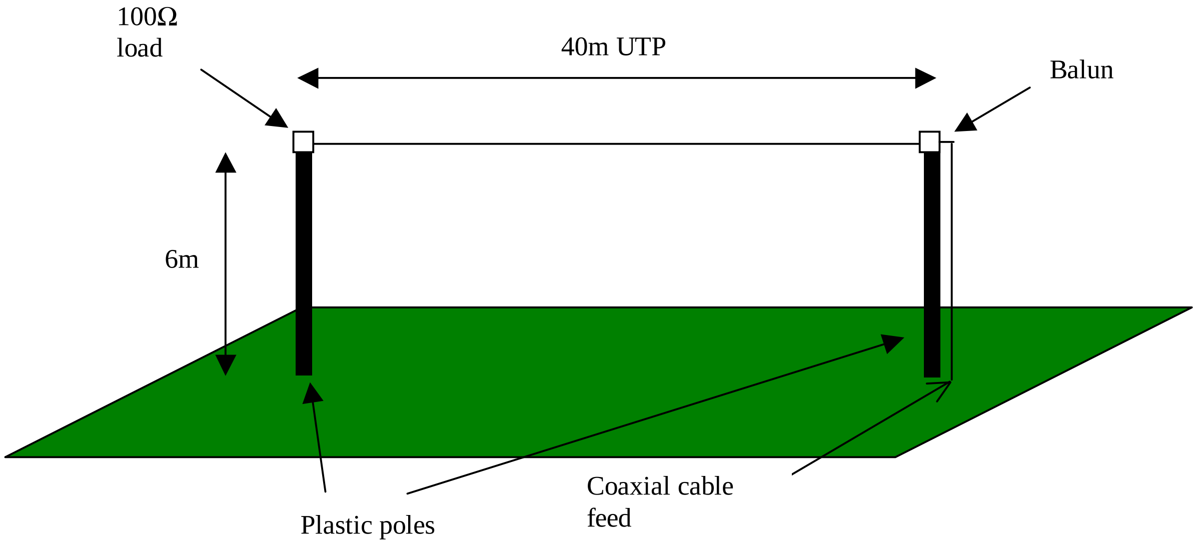


Figure 4.3: Detailed arrangement for horizontal cable measurements

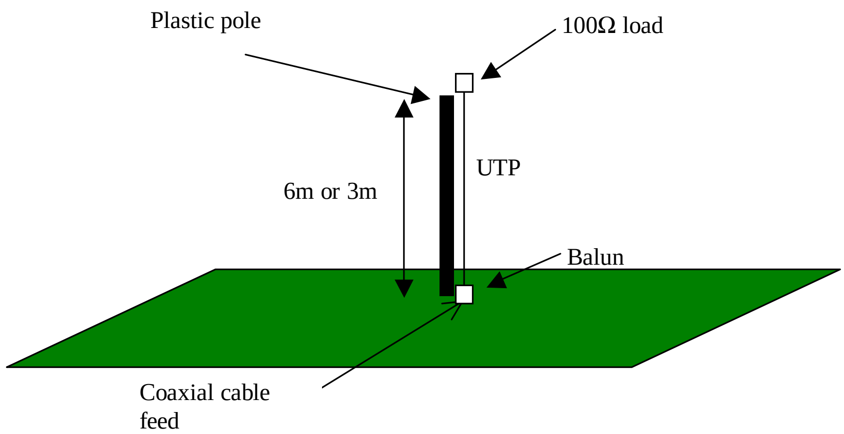


Figure 4.4: Detailed arrangement for vertical cable measurements

The level of emissions from the feed arrangement was determined by replacing the UTP with a 100Ω load and was typically found to be at least 20dB lower than the emissions with the UTP connected.

4.3 Test results

The electric field strength measured in each test configuration is shown in Figures 4.5 to 4.7. Note that in some cases the graph for the balanced configuration is incomplete because the emissions could not be measured above the ambient radio noise floor.

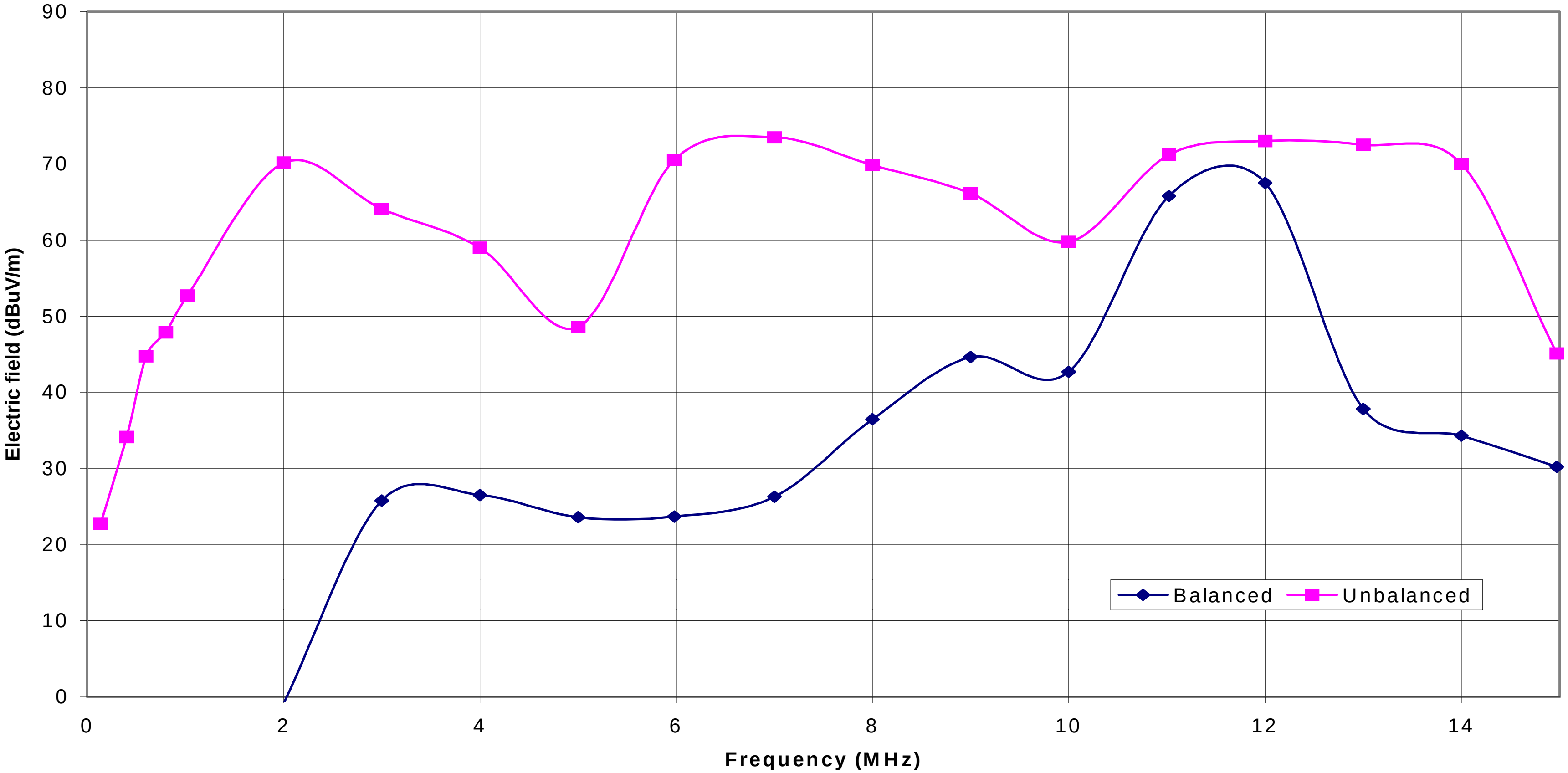


Figure 4.5: Emissions at 130m from horizontal cable

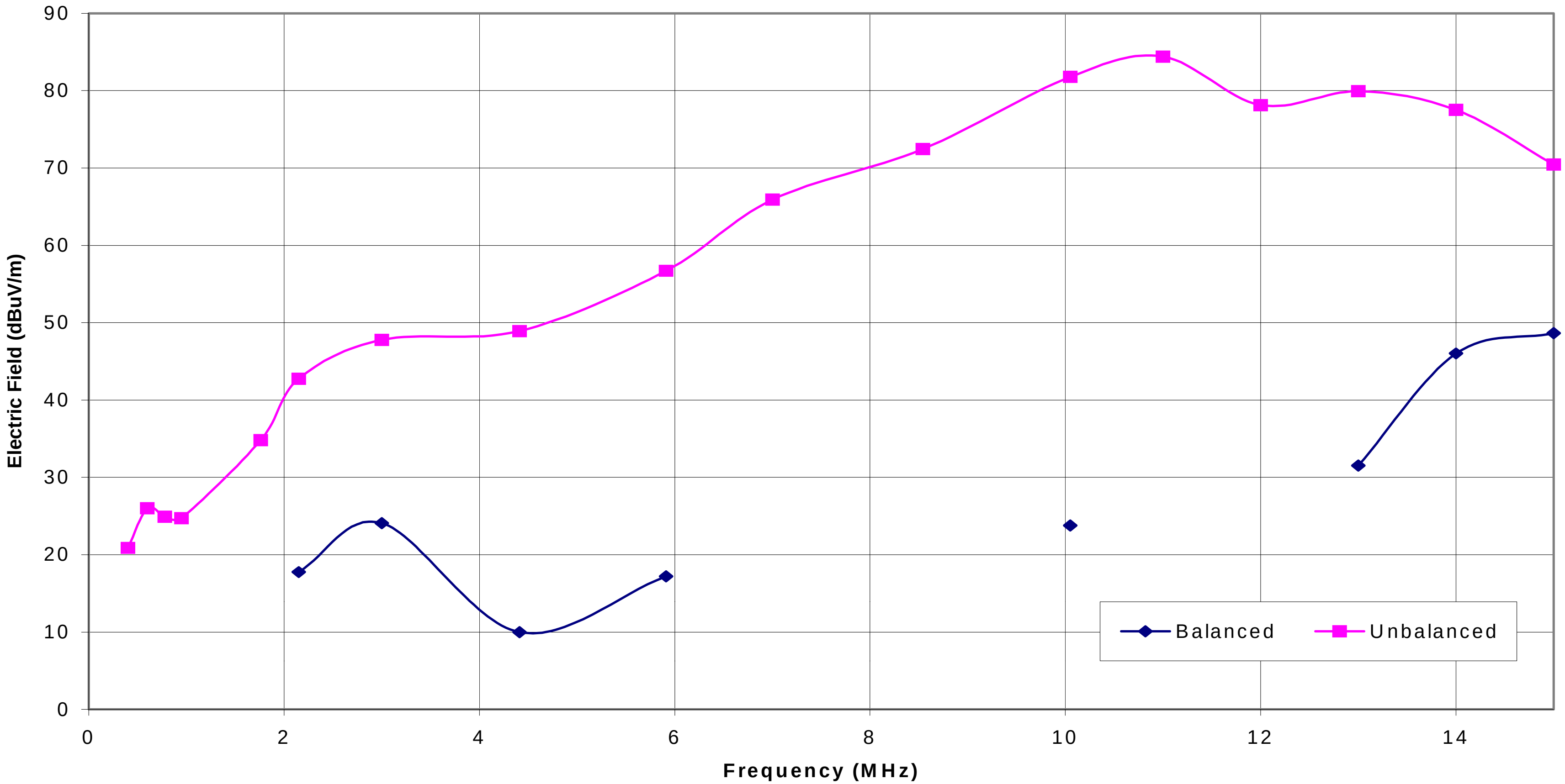


Figure 4.6: Emissions at 130m from 6m vertical cable

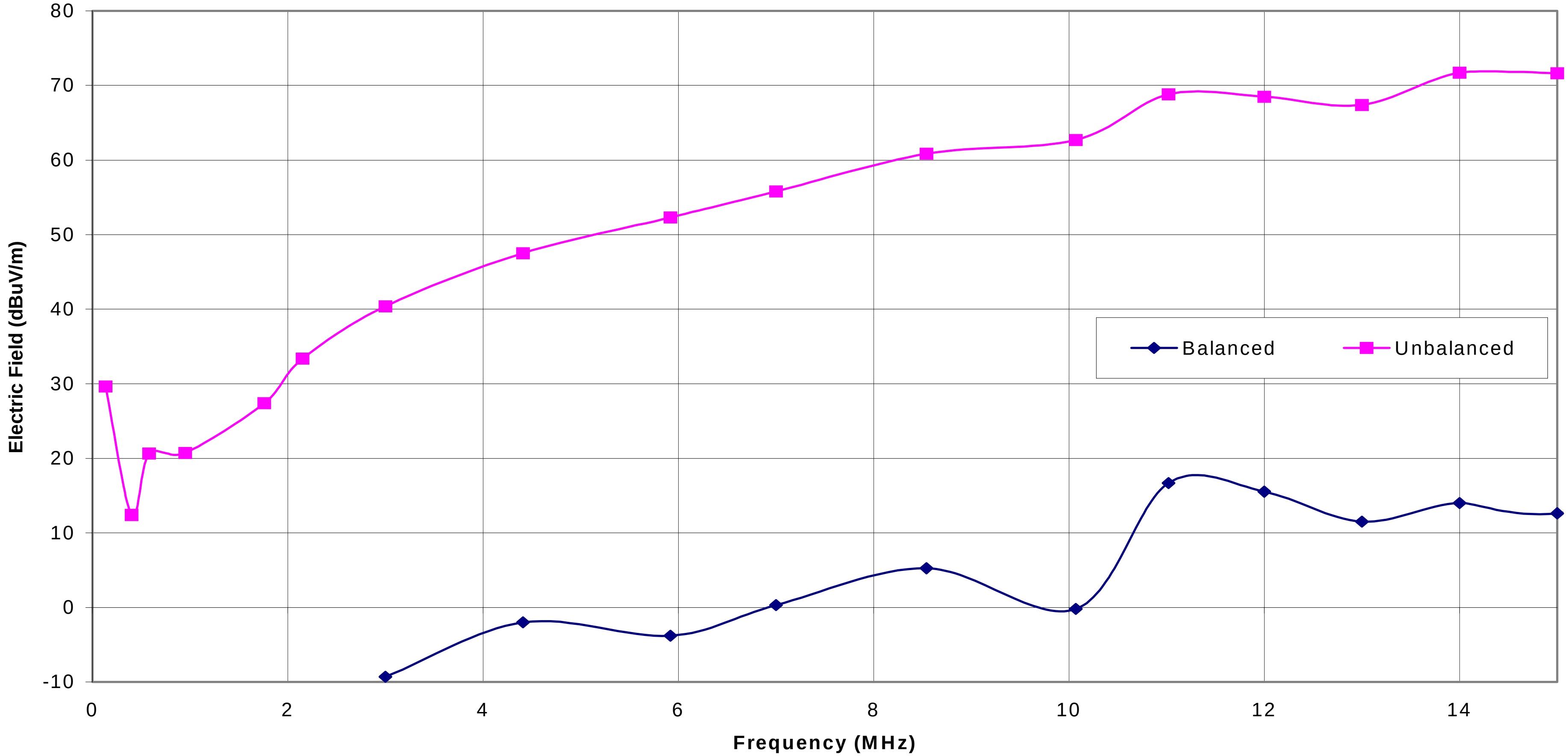


Figure 4.7: Emissions at 130m from 3m vertical cable

The horizontal cable results show the expected resonant structure for emissions from a cable above ground. The emissions from the vertical cables increases steadily with frequency until the cable is a quarter of a wavelength long and thereafter remain at a relatively high level.

The results clearly demonstrate the importance of the balance, not only of the cable itself, but also of the connection points in the system. The difference between the emissions from the well balanced and unbalanced cases typically ranges from 20dB to 50dB over the xDSL frequency range.

To give a direct estimate of emissions from a VDSL system 50dB should be deducted from the electric fields in Figures 4.5 to 4.7, since the input power is typically –20dBm in a 10kHz bandwidth.

4.4 Antenna Efficiency of UTP

To relate the experimental measurements to the modelling results predictions derived in later sections the antenna efficiency of the UTP in the experiments can be estimated. Assuming that the UTP radiates a total power of P_t with a gain of G the electric field at distance d is given by

$$E = \frac{\sqrt{30GP_t}}{d}$$

and hence the total radiated power can be written

$$P_t = \frac{(Ed)^2}{30G}.$$

If the input power is P_{in} then the antenna efficiency can thus be estimated from

$$\eta = \frac{P_t}{P_{in}} = \frac{(Ed)^2}{30GP_{in}}.$$

We can assume a reasonable value for the antenna gain, for example, in the case of the 6m vertical UTP, we can assume that the gain is that of a short vertical monopole, i.e. G=3. Then since the input power is 1W and range is 130m we can derive the following relationship between the radiation efficiency and measured electric field at 130m:

$$\eta = 188E^2,$$

or in decibels:

$$\eta(\mathrm{dB}) = 20\log(188E).$$

The efficiencies for the 6m vertical cable derived from this equation are tabulated in Table 4.1 for both the balanced and unbalanced cases. Below 2MHz the receiver is not in the far field and the above calculation cannot be applied. The table also shows the corresponding "raw" efficiency predicted by NEC (see Table 5.17) for a 6m monopole. In the ground wave propagation model an effective balance parameter of 30dB to 50dB is subtracted from the raw NEC antenna efficiencies to account for the balance of the system. By comparing the measured and NEC antenna efficiencies we can determine the effective balance parameter for the experiments. This is shown in the last two columns of Table 4.1.

For the unbalanced experiments the effective balance of the system ranges from around 10dB to 35dB over the frequency range 2MHz to 10MHz. In the balanced case the effective balance is higher, ranging from 57dB to 73dB. This demonstrates the importance of the quality of the balance at interconnections for the overall balance, and hence emissions, of the system. In the propagation models presented in the following sections the effective balance of the system is a free parameter which can be adjusted to match the measured balance of a particular system. For illustrative purposes balances of 50dB and 30dB have been used in the modelling, corresponding to a ‘typical good’ and ‘an average’ system balance. These balances are consistent with the measurements.

Frequency (MHz)	Measured Efficiency (dB)		NEC Efficiency	Effective Balance (dB)	
	Unbalanced	Balanced		Unbalanced	Balanced
2.2	-55	-79	-19	36	60
3.0	-46	-74	-17	29	57
4.3	-47	-87	-14	33	73
5.9	-40	-79	-11	29	67
7.0	-30	-	-10	20	-
8.5	-25	-	-9	16	-
10.0	-15	-74	-8	7	65

Table 4.1: Comparison of measured antenna efficiencies and the raw NEC model efficiencies for 6m of vertical UTP. The difference between these determines the effective balance parameter used in the NEC models.

5 NEC xDSL LAUNCH MODELS FOR GROUNDWAVE PROPAGATION MODEL

5.1 Methodology

The Numerical Electromagnetics Code (NEC) was used to model the radiation from a number of basic elements in the xDSL scenario. The Sommerfeld-Norton lossy ground model[x] was employed for the simulations with ground parameters ε_r=20.0 and σ=15 mS/m corresponding to average UK ground conditions. The frequency range for all xDSL technologies was considered with spot frequencies at 100 kHz, 200 kHz, 400 kHz, 600 kHz, 800kHz, 1 MHz, 2 MHz, 4 MHz, 6MHz, 8MHz, 10 MHz, 15 MHz, 20 MHz, 25 MHz and 30 MHz. Assuming that the unbalanced component of the current on the wire is the dominant radiating mechanism, the UTP cable was modelled as a single wire with an effective common mode excitation.

For each simulation the elemental radiators were fed using a 1 V, zero impedance, voltage source from both the remote (house) end of the cable and the exchange end of the cable. The feed current (I_{in}), input impedance (Z_{in}), input power (P_{in}), and radiated power (P_{rad}) were determined. The radiated power had to be calculated by integrating the electric field over a hemisphere in the far field since NEC2 is unable to directly determine the component of the power that is absorbed in the lossy ground. From these parameters the antenna efficiency (ε), radiation resistance (R_{rad}) and effective height of th antenna (h_{eff}) were determined from,

$$\varepsilon = \frac{P_{rad}}{P_{in}}$$

$$R_{rad} = \frac{2P_{rad}}{|I_{in}|^2}$$

$$h_{eff} = \frac{c}{\pi f}\frac{1}{|I_{in}|}\sqrt{\frac{P_{rad}}{20}}$$

Figure 5.1: Derived parameters

where c is the velocity of light and f the frequency.

To interface the NEC launch models with the ground wave propagation theory the radiation pattern at a distance of 9km from the source was calculated. This is well into the far field at the lowest frequency considered (100kHz) and close enough to the source for the NEC flat earth lossy ground model to be accurate. The electric field at an elevation of 5 degrees was used to determine the azimuthal radiation patterns presented in Figures 5.5 to 5.8.

5.2 Elemental Radiators

A number of elemental radiating mechanisms were considered. The Drop 1 model shown in Figure 5.2 represents the wiring between the bottom of a telegraph pole and a user's telephone or initial terminal. The effects of underground local feeds have not been considered.

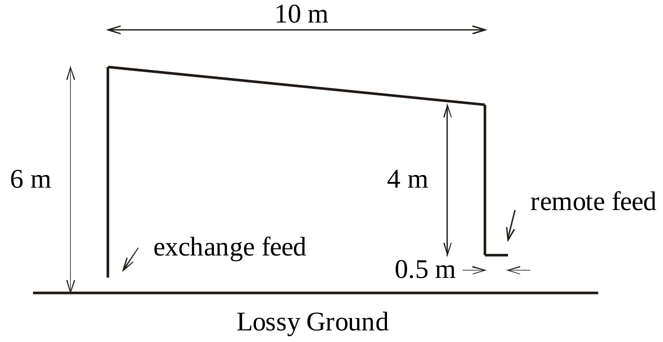


Figure 5.2: Geometry of Drop 1 element

The Drop 2 model in Figure 5.3 adds the possibility of internal house wiring to the Drop 1 model. This would be the case if a splitter were not used to isolate the house wiring.

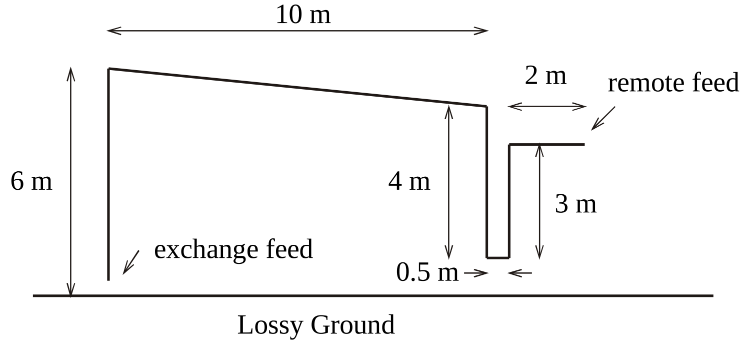


Figure 5.3: Geometry of Drop 2 element

To account for high rise buildings a number of models, Storey N, where N=1, 2, 3, 4, 5, 10, were constructed as shown in Figure 5.4. Each storey was assumed to be 3 m high and a horizontal run 2 m was used.

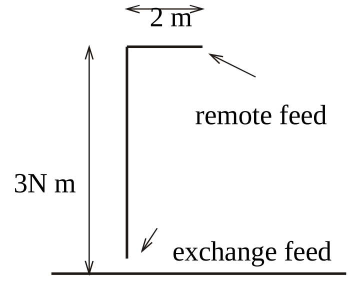


Figure 5.4: Geometry of Storey N elements. N=1, 2, 3, 5 and 10

5.3 NEC Results

Table 5.1 to Table 5.8 present the results obtained when the remote end of the elemental radiator is excited with a 1V source. The results can be normalised to the input current (effective common mode current driving the structure) or the total radiated power. Figure 5.5 and Figure 5.6 show the azimuthal radiation patterns at 5^{o} altitude for a number of the elements at 100kHz and 1MHz respectively. Each pattern is normalised to 0dBμV/m maximum field strength. Over the ADSL band the patterns are essentially omnidirectional allowing a vertical monopole model to be used for ground wave predictions with the parameters given in the tables. Corresponding results for the models in which the exchange end is excited are given in Table 5.9 to Table 5.16 and Figure 5.7 to Figure 5.8.

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	5.76E-07	90	0.000573	0	0.041265	0.001425	5.699533
0.2	1.15E-06	90	0.002336	0.000004	0.155078	0.005455	5.576064
0.4	2.30E-06	90	0.009892	0.000055	0.556749	0.020737	5.435642
0.6	3.46E-06	90	0.023816	0.000271	1.13686	0.045302	5.356079
0.8	4.61E-06	90	0.045394	0.000841	1.853697	0.079183	5.310875
1	5.76E-06	90	0.076052	0.002039	2.681163	0.122762	5.290224
2	1.15E-05	90	0.44683	0.034839	7.796879	0.523155	5.460427
4	2.32E-05	89.98	5.011301	1.0317	20.58747	3.826593	7.383929
6	3.58E-05	89.71	90.86232	35.3557	38.91129	55.30463	18.71418
8	4.42E-05	89.33	258.7865	147.787	57.10769	151.2555	23.2117
10	5.73E-05	89.81	93.77773	49.4477	52.72862	30.13493	8.28851
12	7.02E-05	89.71	175.8035	67.1871	38.21716	27.28704	6.572618
15	8.10E-05	79.3	7520.045	2754.99	36.63529	838.9481	29.15531
20	1.18E-04	88.41	1639.741	650.788	39.68846	93.3115	7.292543
25	1.42E-04	88.47	1894.254	860.893	45.4476	85.92779	5.598455
30	1.67E-04	83.68	9176.075	3858.91	42.05404	278.095	8.39299

Table 5.1: Drop 1 remote transmit model.

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	6.57E-07	90	0.00009	0	0.001522	0.000006	0.380218
0.2	1.31E-06	90	0.0004	0	0.010001	0.000046	0.513857
0.4	2.63E-06	90	0.002083	0.000001	0.066861	0.000404	0.758432
0.6	3.94E-06	90	0.005897	0.000012	0.202209	0.001536	0.986222
0.8	5.25E-06	90	0.012509	0.000056	0.450504	0.004082	1.205798
1	6.57E-06	90	0.022501	0.000191	0.850803	0.00887	1.42205
2	1.32E-05	90	0.175309	0.009935	5.667252	0.114751	2.557341
4	2.65E-05	89.98	4.133414	1.08713	26.30102	3.084846	6.629765
6	4.44E-05	80.26	3750.18	1638.7	43.69657	1666.238	102.7208
8	5.22E-05	89.85	67.67591	32.6455	48.23799	23.95885	9.238136
10	6.70E-05	89.84	90.96989	41.4527	45.56749	18.48263	6.491175
12	9.14E-05	86.27	2969.879	1156.75	38.9494	277.047	20.9429
15	9.86E-05	89.46	460.7455	140.438	30.4806	28.89347	5.410657
20	1.28E-04	88.19	2020.775	880.176	43.55636	107.4405	7.8252
25	1.59E-04	86.76	4497.657	1919.49	42.67755	151.676	7.438063
30	1.95E-04	84.88	8701.375	3556.24	40.86986	187.0001	6.882418

Table 5.2: Drop 2 remote transmit model.

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	6.46E-07	90	0.000199	0	0.010304	0.000098	1.495256
0.2	1.29E-06	90	0.000801	0	0.039179	0.000376	1.464514
0.4	2.58E-06	90	0.003307	0.000005	0.144961	0.001436	1.430615
0.6	3.88E-06	90	0.00775	0.000024	0.305113	0.003149	1.412082
0.8	5.17E-06	90	0.014401	0.000074	0.511461	0.005517	1.401805
1	6.46E-06	90	0.023529	0.000179	0.759237	0.008563	1.397159
2	1.29E-05	90	0.115332	0.002971	2.576199	0.035577	1.423961
4	2.59E-05	90	0.714884	0.060494	8.462028	0.180537	1.603854
6	3.89E-05	89.99	2.565106	0.415596	16.2019	0.548353	1.863461
8	5.21E-05	89.98	7.368827	1.7969	24.38516	1.323163	2.170991
10	6.55E-05	89.97	18.76672	6.00364	31.99089	2.798307	2.525742
12	7.92E-05	89.94	44.60968	17.1662	38.48089	5.473136	2.943596
15	1.01E-04	89.82	155.3221	71.0985	45.77488	14.01582	3.768421
20	1.44E-04	88.74	1578.055	808.504	51.23421	78.20387	6.676141
25	1.54E-04	62.44	35695.69	17235.3	48.28398	1447.988	22.98179
30	1.76E-04	87.82	3351.767	1259.78	37.58555	81.42532	4.541506

Table 5.3: Storey 1 remote transmit model.

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	6.50E-07	90	0.000111	0	0.124497	0.000654	3.860415
0.2	1.30E-06	90	0.000457	0.000002	0.462435	0.002498	3.772958
0.4	2.60E-06	90	0.001991	0.000032	1.60473	0.009438	3.667006
0.6	3.90E-06	90	0.004935	0.000156	3.156719	0.020453	3.598864
0.8	5.20E-06	90	0.009657	0.000479	4.963667	0.035395	3.550765
1	6.51E-06	90	0.016569	0.001148	6.926073	0.054228	3.516024
2	1.30E-05	90	0.108863	0.017839	16.38694	0.21049	3.463597
4	2.61E-05	90	1.128834	0.326427	28.91718	0.958315	3.69518
6	3.93E-05	89.98	5.885712	2.14283	36.40732	2.771908	4.189667
8	5.28E-05	89.95	22.87693	9.38092	41.00603	6.73032	4.896314
10	6.68E-05	89.86	79.25743	34.0799	42.999	15.29517	5.904982
12	8.17E-05	89.6	285.4393	121.16	42.44685	36.26999	7.577638
15	1.11E-04	85.86	4004.987	1496.73	37.37166	242.5908	15.67788
20	1.23E-04	88.26	1869.906	516.756	27.6354	68.08263	6.229161
25	1.65E-04	88.95	1506.492	504.865	33.51262	37.20238	3.683721
30	2.17E-04	86.62	6401.414	2661.7	41.57988	113.1846	5.354437

Table 5.4: Storey 2 remote transmit model.

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	6.53E-07	90	0.000083	0	0.451874	0.001768	6.349483
0.2	1.31E-06	90	0.000355	0.000006	1.621218	0.006751	6.203019
0.4	2.61E-06	90	0.00168	0.000087	5.165732	0.025463	6.023316
0.6	3.92E-06	90	0.004505	0.000422	9.377959	0.055074	5.905589
0.8	5.22E-06	90	0.0095	0.001297	13.65439	0.095108	5.820504
1	6.53E-06	90	0.017661	0.003099	17.54771	0.145397	5.7573
2	1.31E-05	90	0.159014	0.047704	29.9997	0.558654	5.642649
4	2.62E-05	89.99	2.266363	0.866499	38.23302	2.520129	5.992289
6	3.96E-05	89.96	14.4568	5.85939	40.53034	7.47501	6.88012
8	5.35E-05	89.84	74.04116	29.2403	39.49195	20.46117	8.537224
10	6.88E-05	89.21	472.034	167.606	35.50719	70.78358	12.70304
12	8.40E-05	80.64	6828.344	2059.74	30.16456	584.197	30.41164
15	9.44E-05	88.73	1048.116	272.519	26.00084	61.14358	7.870921
20	1.35E-04	89.13	1024.56	352.252	34.38081	38.92938	4.710317
25	1.66E-04	72.79	24504.58	11184.5	45.64249	815.586	17.2479
30	1.92E-04	88.36	2740.847	1387.31	50.61611	75.34713	4.368713

Table 5.5: Storey 3 remote transmit model.

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	6.54E-07	90	0.000069	0.000001	1.072288	0.003439	8.853729
0.2	1.31E-06	90	0.000307	0.000011	3.656138	0.013122	8.647998
0.4	2.62E-06	90	0.001615	0.000169	10.48518	0.049463	8.395
0.6	3.93E-06	90	0.004727	0.000824	17.42048	0.106918	8.228411
0.8	5.23E-06	90	0.010849	0.002528	23.29938	0.184559	8.1081
1	6.54E-06	90	0.021667	0.006037	27.86436	0.282071	8.019006
2	1.31E-05	90	0.243377	0.093074	38.24285	1.084949	7.863503
4	2.63E-05	89.98	4.189215	1.73403	41.39272	5.008933	8.448002
6	3.99E-05	89.9	33.51821	13.1439	39.21421	16.54447	10.23568
8	5.46E-05	89.33	320.7091	108.281	33.763	72.66134	16.08804
10	6.32E-05	82.76	3977.78	1109.01	27.88012	555.9575	35.601
12	7.64E-05	89.04	639.6962	163.267	25.52258	55.98378	9.41437
15	9.92E-05	89.47	457.0851	139.565	30.5337	28.35818	5.360302
20	1.30E-04	76.39	15345.96	7275.44	47.40948	855.2196	22.07752
25	1.65E-04	88.64	1955.634	1071.94	54.81291	78.94709	5.366232
30	2.00E-04	73.91	27724.16	15122.6	54.54665	755.5806	13.83441

Table 5.6: Storey 4 remote transmit model.

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	6.55E-07	90	0.000059	0.000001	2.039743	0.00565	11.34909
0.2	1.31E-06	90	0.000284	0.000018	6.519285	0.02156	11.08499
0.4	2.62E-06	90	0.001666	0.000279	16.74188	0.081247	10.7593
0.6	3.93E-06	90	0.005322	0.001356	25.48834	0.175615	10.54558
0.8	5.24E-06	90	0.013129	0.004164	31.71592	0.303217	10.39269
1	6.55E-06	90	0.027753	0.009951	35.85473	0.463566	10.28009
2	1.31E-05	90	0.359464	0.154456	42.96846	1.79462	10.11341
4	2.64E-05	89.97	7.252661	3.04276	41.9537	8.738536	11.15837
6	4.02E-05	89.76	85.57619	30.8239	36.01925	38.11556	15.53608
8	5.40E-05	83.67	2974.939	857.147	28.81225	588.2308	45.77468
10	6.41E-05	89.24	422.958	108.39	25.62666	52.79861	10.97116
12	7.89E-05	89.6	275.629	79.7697	28.94097	25.6362	6.370697
15	1.05E-04	88.43	1436.862	638.241	44.41909	116.6844	10.87318
20	1.30E-04	88.91	1232.985	667.65	54.14908	79.03603	6.711567
25	1.65E-04	75.59	20554.34	10711.7	52.11405	784.8379	16.91965
30	2.02E-04	87.89	3718.326	1982.45	53.31566	97.42369	4.967666

Table 5.7: Storey 5 remote transmit model.

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	6.57E-07	90	0.000045	0.000005	11.79867	0.024455	23.61164
0.2	1.31E-06	90	0.000307	0.000081	26.26256	0.093319	23.06193
0.4	2.63E-06	90	0.002798	0.001216	43.45205	0.35207	22.39732
0.6	3.94E-06	90	0.011907	0.005933	49.82738	0.763455	21.98781
0.8	5.26E-06	90	0.035146	0.018317	52.11546	1.325244	21.72698
1	6.57E-06	90	0.083704	0.044135	52.72728	2.042602	21.5791
2	1.32E-05	89.99	1.556302	0.760504	48.86609	8.754848	22.33756
4	2.71E-05	88.86	269.2683	93.1224	34.5835	253.4867	60.09786
6	3.93E-05	89.79	72.92701	22.5384	30.90542	29.23807	13.60707
8	5.41E-05	89.34	310.2985	161.198	51.94933	110.1638	19.80938
10	6.42E-05	89.09	510.5219	291.606	57.1192	141.33	17.94976
12	8.06E-05	89.38	432.8396	231.937	53.58498	71.47164	10.63719
15	9.68E-05	88.94	893.4781	444.982	49.80335	95.05467	9.813792
20	1.30E-04	88.7	1477.868	800.429	54.16106	94.4785	7.338003
25	1.65E-04	88.28	2481.604	1341.92	54.0747	98.6431	5.998391
30	2.02E-04	87.53	4339.384	2432.29	56.0515	119.6812	5.505961

Table 5.8: Storey 10 remote transmit model.

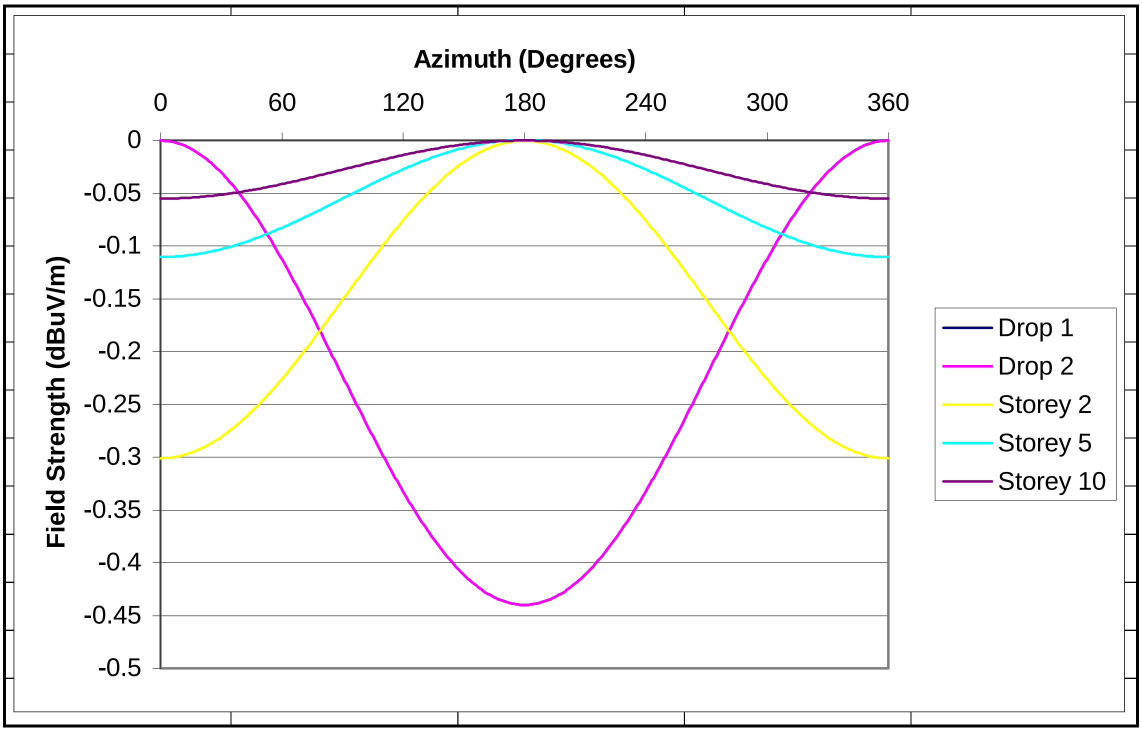


Figure 5.5: Azimuthal field strength for elemental radiators with remote end excitation at 0.1 MHz.

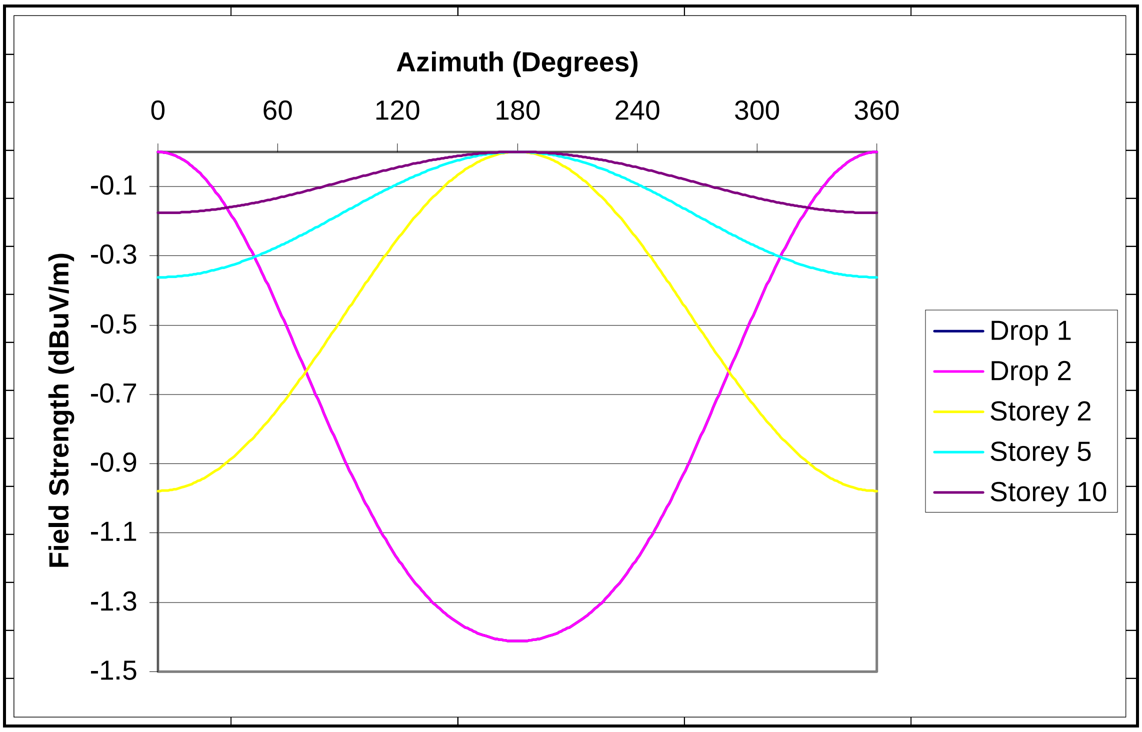


Figure 5.6: Azimuthal field strength for elemental radiators with remote end excitation at 1 MHz.

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	6.74E-07	90	0.01093	0.000001	0.006391	0.003072	8.368447
0.2	1.35E-06	90	0.0438	0.000011	0.024381	0.011739	8.1795
0.4	2.70E-06	89.99	0.176226	0.000162	0.091679	0.044394	7.953222
0.6	4.05E-06	89.99	0.399559	0.000789	0.197467	0.096334	7.810524
0.8	5.40E-06	89.98	0.716675	0.002432	0.339397	0.167	7.71276
1	6.75E-06	89.98	1.131019	0.005839	0.516229	0.256437	7.645952
2	1.35E-05	89.96	4.846936	0.093442	1.927849	1.022184	7.632659
4	2.73E-05	89.89	26.54909	2.29138	8.630729	6.146287	9.358103
6	4.27E-05	89.4	222.9784	67.529	30.285	73.99835	21.64717
8	5.02E-05	88.77	539.3448	299.178	55.47064	236.9927	29.05487
10	6.67E-05	89.49	295.89	127.124	42.96326	57.1798	11.41728
12	8.27E-05	89.16	603.3289	215.546	35.72612	63.0566	9.991379
15	8.76E-05	72.13	13437.46	4874.5	36.27546	1270.947	35.88507
20	1.39E-04	87.45	3101.726	1228.48	39.60634	126.7799	8.500345
25	1.62E-04	88.03	2792.345	1322.55	47.36342	100.5478	6.056025
30	1.92E-04	79.82	16934.6	8078.85	47.70618	439.9227	10.55622

Table 5.9: Drop 1 exchange transmit model

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	6.75E-07	90	0.011113	0.000001	0.00586	0.002856	8.068342
0.2	1.35E-06	90	0.044553	0.00001	0.022364	0.010922	7.889562
0.4	2.70E-06	89.99	0.179443	0.000151	0.084213	0.041404	7.680741
0.6	4.05E-06	89.99	0.407371	0.00074	0.181758	0.090141	7.555296
0.8	5.41E-06	89.98	0.731644	0.002292	0.313297	0.156903	7.475949
1	6.76E-06	89.98	1.156144	0.00553	0.47834	0.242141	7.429765
2	1.35E-05	89.96	5.008984	0.092361	1.843913	1.006463	7.573739
4	2.75E-05	89.87	30.99129	3.05423	9.855124	8.097955	10.7416
6	4.93E-05	74.09	6759.354	2848.55	42.14234	2343.367	121.8177
8	5.30E-05	89.64	167.9626	61.683	36.72425	43.92954	12.50921
10	6.86E-05	89.46	321.4179	85.5252	26.60872	36.33954	9.10188
12	9.51E-05	84.11	4881.851	1538.28	31.51018	339.8688	23.19615
15	1.01E-04	89.24	664.7632	346.918	52.1867	68.32283	8.320187
20	1.30E-04	88.85	1305.827	626.961	48.01256	73.69448	6.480804
25	1.60E-04	84.92	7101.685	3069.74	43.22552	238.7431	9.33183
30	1.96E-04	83.28	11490.9	5642.42	49.10338	292.8081	8.612152

Table 5.10: Drop 2 exchange transmit model

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	3.99E-07	90	0.003586	0	0.001769	0.000796	4.260898
0.2	7.98E-07	90	0.014347	0.000001	0.006746	0.003038	4.161007
0.4	1.60E-06	90	0.057413	0.000015	0.025357	0.011424	4.034485
0.6	2.39E-06	89.99	0.129249	0.000071	0.054553	0.02459	3.946096
0.8	3.19E-06	89.99	0.229915	0.000215	0.093527	0.042181	3.876252
1	3.99E-06	89.99	0.359469	0.000509	0.141679	0.063937	3.817836
2	7.98E-06	89.98	1.44169	0.007303	0.506592	0.229111	3.613553
4	1.60E-05	89.96	5.784452	0.103422	1.787931	0.809718	3.396631
6	2.40E-05	89.94	13.17742	0.497355	3.774297	1.725383	3.305467
8	3.21E-05	89.91	24.37662	1.57599	6.46517	3.061194	3.30215
10	4.02E-05	89.88	41.41532	4.0577	9.797582	5.011464	3.380055
12	4.85E-05	89.84	68.69199	9.35988	13.62587	7.954781	3.548741
15	6.13E-05	89.72	151.7971	30.321	19.97469	16.15193	4.045408
20	8.52E-05	88.84	865.108	278.574	32.20107	76.82209	6.616898
25	9.21E-05	73.51	13065.03	6468.99	49.51378	1526.362	23.59555
30	1.13E-04	88.91	1068.732	741.418	69.37361	116.8806	5.441159

Table 5.11: Storey 1 exchange transmit model

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	6.67E-07	90	0.009778	0.000001	0.006632	0.002919	8.157273
0.2	1.33E-06	90	0.039144	0.00001	0.025278	0.011132	7.965358
0.4	2.67E-06	89.99	0.156985	0.000149	0.094806	0.041859	7.722792
0.6	4.00E-06	89.99	0.354564	0.000721	0.203306	0.090099	7.55354
0.8	5.33E-06	89.99	0.633337	0.002199	0.347179	0.154571	7.420193
1	6.67E-06	89.98	0.995042	0.00521	0.523571	0.234345	7.30919
2	1.33E-05	89.96	4.127323	0.075077	1.819024	0.843063	6.931727
4	2.68E-05	89.92	18.59174	1.09275	5.87761	3.04948	6.591653
6	4.04E-05	89.86	50.64735	5.56694	10.99157	6.829613	6.576399
8	5.43E-05	89.75	119.4794	19.5335	16.34884	13.24404	6.868495
10	6.89E-05	89.53	280.3727	59.9476	21.3814	25.27923	7.591425
12	8.48E-05	89.01	735.7886	189.991	25.82141	52.89774	9.151214
15	1.17E-04	83.38	6734.535	2126.73	31.57946	311.5315	17.76647
20	1.22E-04	88.8	1276.088	546.309	42.81123	72.97173	6.448946
25	1.68E-04	89.4	874.617	430.282	49.19662	30.56782	3.339132
30	2.26E-04	86.5	6900.94	3236.73	46.90274	126.7406	5.666019

Table 5.12: Storey 2 exchange transmit model

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	6.73E-07	90	0.010313	0.000001	0.012668	0.005773	11.47198
0.2	1.35E-06	90	0.041307	0.00002	0.048256	0.022021	11.20297
0.4	2.69E-06	89.99	0.166053	0.0003	0.180598	0.082817	10.86277
0.6	4.04E-06	89.99	0.376278	0.001453	0.386215	0.178342	10.62716
0.8	5.38E-06	89.99	0.674751	0.004436	0.65749	0.306206	10.4438
1	6.73E-06	89.98	1.065062	0.010523	0.988036	0.464683	10.29248
2	1.35E-05	89.96	4.566124	0.153263	3.356523	1.688534	9.809938
4	2.71E-05	89.9	23.14429	2.34534	10.13356	6.402484	9.55115
6	4.10E-05	89.79	76.42419	13.2895	17.38913	15.84376	10.01657
8	5.55E-05	89.49	246.649	58.0684	23.54293	37.6522	11.58101
10	7.21E-05	88.29	1079.2	301.215	27.91095	115.7467	16.2441
12	8.63E-05	75.9	10518.1	3190.18	30.33038	856.0445	36.8136
15	9.48E-05	89.07	767.7289	241.328	31.43401	53.75531	7.380075
20	1.39E-04	89.22	947.9237	434.872	45.87627	45.13352	5.071787
25	1.69E-04	67.64	32117.28	16755.1	52.16849	1175.617	20.70782
30	1.94E-04	88.88	1899.991	1217.64	64.08662	64.72748	4.049156

Table 5.13: Storey 3 exchange transmit model

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	6.76E-07	90	0.010661	0.000002	0.020294	0.009463	14.68751
0.2	1.35E-06	90	0.042736	0.000033	0.077249	0.036096	14.34306
0.4	2.71E-06	89.99	0.172241	0.000497	0.28848	0.135811	13.91069
0.6	4.06E-06	89.99	0.391683	0.00241	0.615251	0.292687	13.6142
0.8	5.41E-06	89.99	0.705396	0.007366	1.044215	0.503103	13.38689
1	6.77E-06	89.98	1.119014	0.017501	1.563975	0.764721	13.20362
2	1.35E-05	89.96	4.983587	0.258786	5.192766	2.81931	12.67602
4	2.73E-05	89.88	29.0573	4.26081	14.66348	11.46273	12.77984
6	4.15E-05	89.66	124.8396	28.9163	23.16276	33.63001	14.59331
8	5.74E-05	88.49	753.6973	214.518	28.46209	130.3734	21.54994
10	6.22E-05	79.39	5721.782	1696.76	29.6544	877.9777	44.73868
12	7.72E-05	89.21	529.3048	147.148	27.80024	49.3482	8.838851
15	1.02E-04	89.52	426.9389	178.787	41.87648	34.19047	5.885762
20	1.30E-04	71.16	21028.21	11329.7	53.87858	1336.188	27.59594
25	1.69E-04	89.23	1129.507	615.166	54.46323	43.20077	3.969604
30	2.09E-04	69.62	36412.68	22019.7	60.47262	1006.627	15.96815

Table 5.14: Storey 4 exchange transmit model.

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	6.78E-07	90	0.010909	0.000003	0.029506	0.013985	17.85581
0.2	1.36E-06	90	0.043774	0.000049	0.112219	0.053352	17.43765
0.4	2.71E-06	89.99	0.176927	0.00074	0.418136	0.200852	16.91684
0.6	4.07E-06	89.99	0.403842	0.003592	0.889444	0.433328	16.56528
0.8	5.43E-06	89.98	0.730691	0.010997	1.505028	0.746012	16.30138
1	6.79E-06	89.98	1.16554	0.026186	2.246684	1.136485	16.0962
2	1.36E-05	89.95	5.420715	0.39492	7.285386	4.26982	15.5997
4	2.74E-05	89.84	37.43713	7.1983	19.2277	19.13694	16.51269
6	4.21E-05	89.34	242.5481	67.5189	27.83732	76.19912	21.96672
8	5.55E-05	79.83	4902.922	1472.68	30.03678	954.8093	58.31895
10	6.51E-05	89.32	388.118	102.002	26.28118	48.09982	10.4716
12	8.13E-05	89.61	273.4482	102.073	37.32809	30.85652	6.989299
15	1.10E-04	87.4	2499.006	1336.15	53.46726	220.1782	14.9361
20	1.33E-04	89.42	668.1256	325.035	48.64879	36.97792	4.59074
25	1.69E-04	70.7	27964.41	16237	58.06309	1133.74	20.33565
30	2.08E-04	88.5	2722.767	1655.53	60.80322	76.32626	4.397007

Table 5.15: Storey 5 exchange transmit model.

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	6.84E-07	90	0.011566	0.000011	0.099175	0.049096	33.45509
0.2	1.37E-06	90	0.046663	0.000175	0.37559	0.187532	32.69257
0.4	2.73E-06	89.99	0.191752	0.002654	1.384081	0.709757	31.80067
0.6	4.10E-06	89.99	0.447967	0.013012	2.904588	1.545764	31.28684
0.8	5.47E-06	89.98	0.835618	0.040401	4.834889	2.698013	31.00084
1	6.84E-06	89.98	1.384355	0.098019	7.08051	4.186209	30.89241
2	1.37E-05	89.93	8.771776	1.76909	20.16798	18.73586	32.67746
4	2.87E-05	87.73	567.4104	198.175	34.92622	481.6326	82.83986
6	4.06E-05	89.74	91.45986	24.2425	26.50616	29.38474	13.64115
8	5.70E-05	88.66	665.7623	384.4	57.73832	236.8137	29.04389
10	6.53E-05	89.11	509.5467	280.853	55.11821	131.5561	17.31797
12	8.42E-05	89.1	658.9545	314.811	47.77432	88.79334	11.85633
15	9.85E-05	89.26	636.748	322.212	50.60275	66.46672	8.206392
20	1.33E-04	89.28	838.6189	452.162	53.91746	51.2011	5.401956
25	1.69E-04	89.02	1446.894	856.564	59.20019	59.6797	4.665677
30	2.09E-04	88.26	3165.259	2032.27	64.20549	93.13651	4.857134

Table 5.16: Storey 10 exchange transmit model.

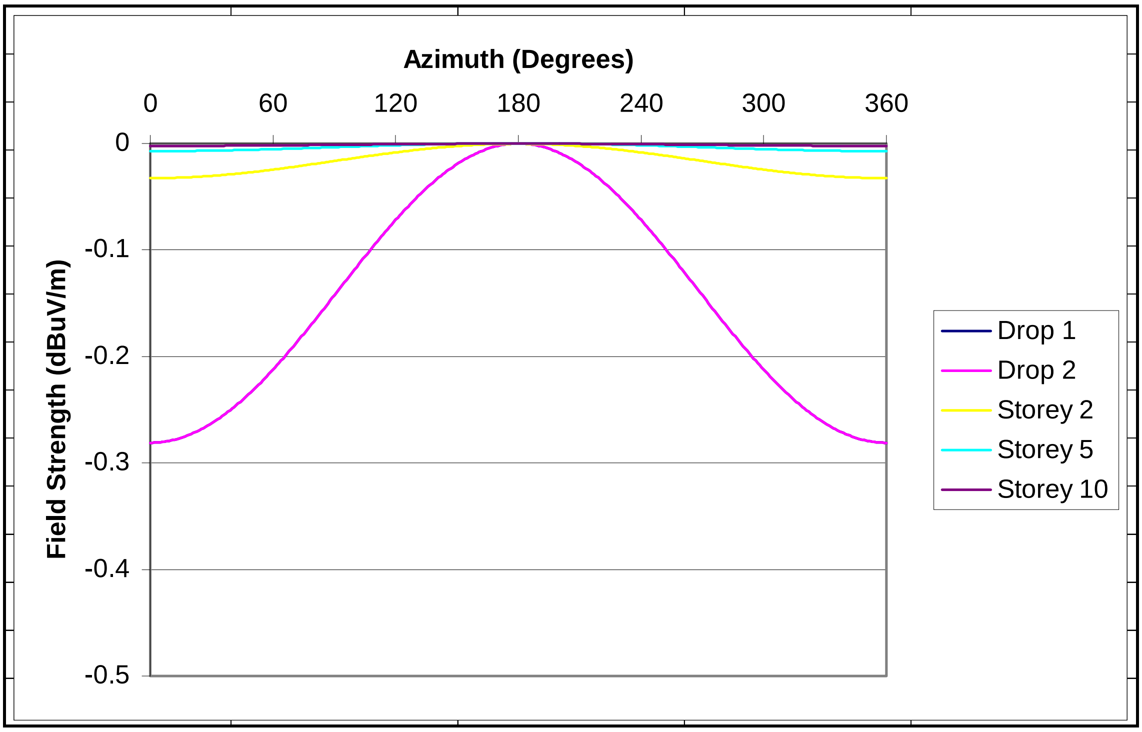


Figure 5.7: Azimuthal field strength for elemental radiators with exchange end excitation at 0.1 MHz.

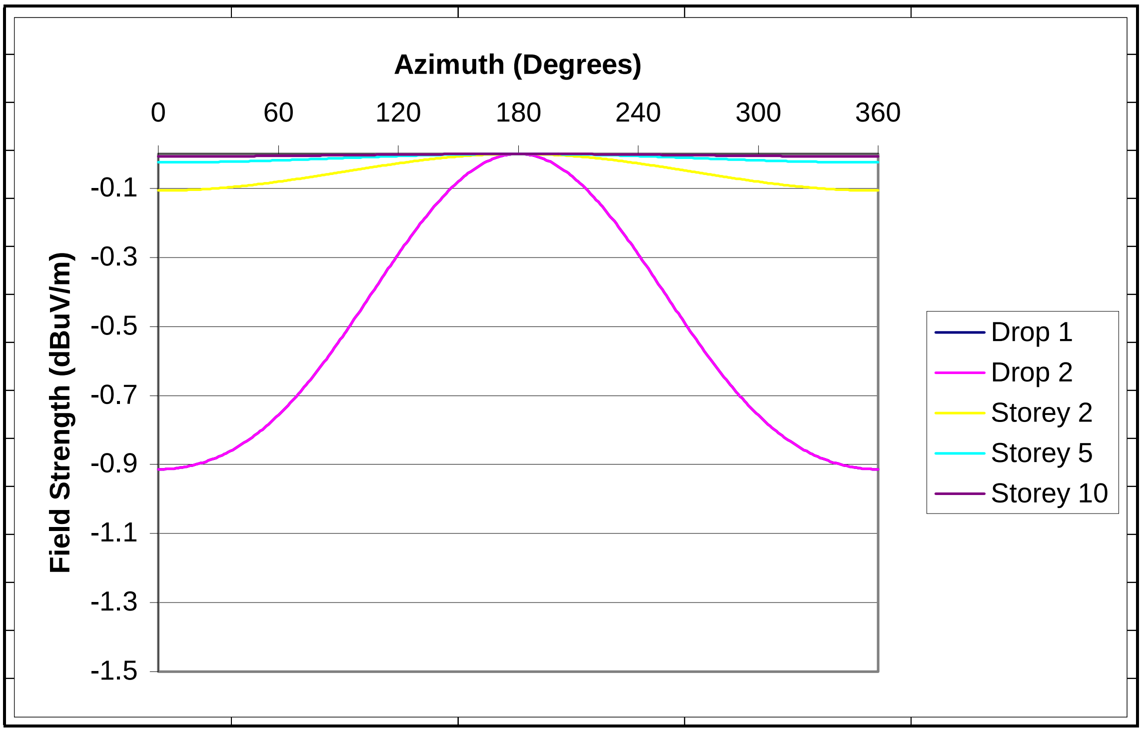


Figure 5.8: Azimuthal field strength for elemental radiators with exchange end excitation at 1 MHz.

5.4 Vertical Monopole Validation Case

To validate the model a test case consisting of a 6m vertical monopole above lossy ground was simulated. The results are given in Table 5.17. Good agreement was obtained with both accepted monopole theory and also with the experimental results in section 4 when the cable balance is accounted for.

Frequency (MHz)	Current Magnitude (A)	Current Phase (Degrees)	Input Power (nW)	Radiated Power (nW)	Antenna Efficiency (%)	Radiation Resistance (Ohms)	Effective Height (m)
0.1	6.61E-07	90	0.009084	0	0.004079	0.001698	6.220937
0.2	1.32E-06	90	0.036348	0.000006	0.015553	0.006475	6.074788
0.4	2.64E-06	89.99	0.145591	0.000085	0.058385	0.02434	5.889033
0.6	3.96E-06	89.99	0.328267	0.000412	0.125357	0.052364	5.758478
0.8	5.29E-06	89.99	0.585073	0.001254	0.214389	0.089773	5.654896
1	6.61E-06	89.98	0.916825	0.002969	0.323851	0.135992	5.567978
2	1.32E-05	89.97	3.735632	0.04244	1.136076	0.485513	5.260317
4	2.65E-05	89.93	15.80347	0.596144	3.772235	1.698637	4.919621
6	3.99E-05	89.89	38.90184	2.83944	7.298986	3.572636	4.756467
8	5.34E-05	89.83	79.08464	8.89536	11.2479	6.235271	4.712801
10	6.72E-05	89.75	148.8185	22.5811	15.17358	9.994383	4.773307
12	8.14E-05	89.62	273.1623	51.1389	18.72107	15.42654	4.941905
15	1.04E-04	89.24	692.7443	159.075	22.96302	29.45009	5.462525
20	1.50E-04	86.44	4641.825	1261.77	27.18263	112.7644	8.016732
25	1.45E-04	69.92	24804.24	7237.98	29.18041	693.21	15.90134
30	1.79E-04	87.91	3260.714	1108.05	33.98182	69.19721	4.186629

Table 5.17: Vertical dipole exchange transmit model.

6 GROUNDWAVE PROPAGATION OF CUMULATIVE ADSL EMISSIONS

6.1 Assumptions regarding groundwave propagation model

For frequencies up to at least 30 MHz both sky and ground wave propagation are applicable, with the ground wave tending to dominate at the lower frequencies, and the sky wave becoming increasingly important for frequencies above about 3 MHz. For the ADSL technology, which utilises frequencies between 25 kHz and 1.1 MHz for digital data transmission, the ground wave is certainly the most serious electromagnetic threat. In the following, a detailed and comprehensive methodology for the assessment of the cumulative radiation effect resulting from the widespread application of the ADSL technology is presented and example calculations are given.

6.2 Ground wave propagation theory

The fundamental problem of radiation from a short vertical current element above a flat lossy earth was solved by Sommerfeld in 1909. Later work by Sommerfeld and other researches led to the development of the exact theoretical formulae by Norton[xi,xii] for a spherical earth. For distances close to the transmitter where flat earth propagation is applicable the expressions simplify. Thus, for distances d less than d_{max}, where

$$d_{\max} = f^{-\frac{1}{3}}$$

and d_{max} is in km and f is in MHz, the electric field E in mV/m is given by the following expression:

$$E = \frac{FM\sqrt{P_t}}{d} A$$

where FM is the so-called figure of merit depending on the type of antenna used, Pt is the transmitted power in kW, and A is the surface wave attenuation factor. The surface attenuation factor is given by the expression

$$A = \frac{2+0.3p}{2+p+0.6p^2} - \sin b\sqrt{\frac{1}{2}p}\,\exp(-5p/8)$$

where p is the numerical distance given by

$$p = \frac{0.582d(km) f^2 (MHz)\cos b}{\sigma(mS/m)}$$

with σ being the conductivity, ε_r the relative permittivity and

$$b = \tan^{-1}\frac{(\varepsilon_r - 1)f(MHz)}{18\sigma(mS/m)}$$

The above formulae apply for vertical polarisation. In the case of horizontal polarisation the surface attenuation factor approaches

$$\left| \left[\frac{1}{\varepsilon_r - j(\sigma/\omega\varepsilon_o)} \right]^2 A(p) \right|$$

where the numerical distance p is now given by

$$p = \frac{60\pi\sigma(mS/m)d(km)}{\cos b}$$

Since σ now occurs in the numerator instead of the denominator of p, the numerical distance is much larger for horizontal polarisation than for vertical polarisation at low frequencies. The implication is much smaller electric field strengths for horizontal polarisation, typically 115 dB and 93 dB less than for vertical polarisation at 0.1 and 1.0 MHz, respectively.

The above expressions can be very easily evaluated to provide predictions of electric field strength at distances shorter than d_{max} (flat earth approximation). For the ADSL technology where f varies between 0.1 and 1.1 MHz the maximum distance is typically 215 to 97 km respectively.

For a spherical earth and at distances larger than d_{max}, the full solution of Norton must be used to evaluate the electric field. However, such is the complication of the resulting formulae that it is common practice to use instead either ITU software run on a personal computer or charts of field strength versus distance for specified values of ground electrical parameters and operating frequencies. In this study the PC version of the well known ITU GRWAVE software was used to estimate the electric field resulting from cumulative ADSL emissions. Nevertheless, Norton's solutions for vertically and horizontally polarised waves apply to a very simple radiating configuration, i.e., a short current filament. It is therefore necessary to assess the radiative properties of more complex structures associated with the metallic copper telephone access network.

6.3 Radiative properties of ADSL complex structures

Before the cumulative interference effect of the widespread application of the ADSL technology can be assessed, the radiative properties of single interference sources must be assessed. The radiative properties of ADSL distribution configurations associated with typical residential and commercial buildings found in the UK were evaluated using NEC. More specifically, for a variety of distribution configurations the radiation efficiency (ratio of radiated to input power), radiation resistance, input impedance and equivalent short monopole height were determined. The calculations have been carried out for up-stream and down-stream transmission, i.e., from the ADSL Terminal Unit-Central office[3] (ATU-C) or Digital Subscriber Line Access Module (DSLAM) to the ADSL Terminal Unit-Remote (ATU-R) and vice versa. This was accomplished by exciting the radiating configurations at different points. A detailed description of the modelling assumptions, geometry and radiation patterns can be found in section 5. It must be noted that over the entire ADSL band the radiation patterns of the individual radiative elements considered remained essentially omnidirectional (see Figures 5.5 and 5.8 in section 5).

Other important factors which need to be considered in the context of ingress and egress issues of metallic access cables are the loss per unit length and balance. The cables used in the access networks are unshielded twisted pairs (UTP) of various gauges and twist lengths. Thinner pairs of diameter 0.32 mm are normally found nearer the exchanges, and thicker pairs of diameter 0.4 to 0.5 mm nearer the customers. Most pairs are twisted to improve their longitudinal balance as well as to reduce crosstalk, emissions and pickup. Typical losses at frequencies of 0.1 and 1.0 MHz for pairs 0.4-0.5 mm in diameter, assuming source and termination impedances of 100Ω, range from 7-10 to 20-23 dB/km, respectively[xiii]. The cable balance relates the degree of coupling between the common mode (cable to ground) and differential mode (between the two wires of the pair) signals. The balance is expressed as the decibel ratio of the common-mode and differential-mode voltages as

$$balance(dB) = 20\log\frac{V_{common}}{V_{differential}}$$

The balance of UTP generally decreases with frequency, although resonant features may be present, and is typically 50 dB for frequencies below 1MHz. Nevertheless, the balance varies from pair to pair and will depend on many factors such as cable type, its quality and age, the installation configuration and external factors such as humidity and condensation. For old installations balance values of less than 30 dB are quite common. In order to assess the effect of balance on radiative emissions, a series of emission tests for UTP cables were performed at Whyteleafe laboratory. The experimental test layouts and the measurements for vertically and horizontally oriented cables for balanced and unbalanced conditions can be seen in Section 4. The experimental results agree well with the measurements reported by Czajkowski[xiii]. Indeed, radiative emissions from balanced cables were consistently 30 to 50 dB less

[3] Central Office is the American expression for telephone exchange.

than those emanating from unbalanced cables. Thus, for our practical calculations, it is not unreasonable to assume average differences between balanced and unbalanced cables of the order of 30 to 50 dB for radiative emissions.

6.4 Calculation strategy of cumulative emissions

In order to calculate the cumulative ground wave interference resulting from the application of the ADSL technology to numerous single users, knowledge of the physical distribution of the single sources and the manner and geometry of the propagation path by which the interference reaches the victim receiver is required. Ideally, one would have to consider the particular location of each interference source, determine the propagation from each source to the victim receiver, and perform a power summation[4]. This is however, impractical for widespread systems, and is certainly not possible when the system is yet unrealised and the locations are not known in detail. Instead, one can realistically estimate the density D_i of potential installations, treat the sources as being uniformly spread over a known area and perform the RSS summation method to evaluate the electric field as a function of distance. Thus, the total electric field strength due to m different types of radiating sources is given by

$$E = \sqrt{A\sum_{i=1}^{m} p_i D_i M_{pi} L_i E_i^2}$$

where A is the area in m^2 including all radiating sources, p_i is the percentage of building type associated with the ith radiating source within A, D_i is the density of installations per unit area, M_{pi} is the fraction of market penetration, L_{ui} is the percentage of installed lines used concurrently and E_i is the electric field strength due to the i-type single installation. In our study seventeen different basic radiating elements associated with common building types found in the UK, including bungalow, semi-detached and detached residential properties, one to ten storey business buildings and an exchange main distribution frame (MDF) drop can be selected. Therefore, if the percentage coverage and densities of different types of buildings are known, it is possible to achieve a realistic prediction of the cumulative interference effect. Market analysis suggests that new technologies, i.e., cable TV, internet, etc, tend asymptotically around a 20% domestic market penetration percentage. Thus, in our calculations 20% market penetration has been assumed. The

[4] It can be safely assumed that the signals from the various interference sources are uncorrelated and so their cumulative effect on the receiver can be assessed by power addition, or equivalently by the Root of the Sum of Squares (RSS) method in terms of the electric field strength. Furthermore, through the Central Limit Theorem the cumulative xDSL electric field amplitude is expected to follow the normal distribution.

percentage of installed lines used concurrently has been set to 30%, which is thought to reflect the usage habits of xDSL customers on a busy weekday afternoon.

6.5 Ground wave electric field calculations

Using the computer implementation of ITU-R P368 the following electric field values were obtained for values of ground parameters typical of British ground. The tabulated values assume a short monopole antenna having an unattenuated electric field of 300 mV/m.

Distance (km)	100 kHz	200 kHz	500 kHz	700 kHz	1 MHz
10	89.45	89.40	89.01	88.58	87.68
25	81.44	81.30	80.40	79.41	77.39
50	75.30	75.02	73.30	71.45	67.76
75	71.69	71.27	68.74	66.07	60.96
100	69.05	68.47	65.16	61.73	55.41
200	62.25	61.08	54.76	48.71	39.43
300	57.77	55.97	46.85	38.75	28.02
400	54.15	51.73	39.94	30.15	18.19
500	51.01	47.92	33.55	22.22	8.96

Table 6.1a: E-field (dBμV/m) for typical UK wet ground ε_r=20, σ=15mS/m. Vertical polarisation

Distance (km)	100 kHz	200 kHz	500 kHz	700 kHz	1 MHz
10	-5.65	-5.66	-5.68	-5.69	-5.71
25	-21.78	-21.76	-21.83	-21.87	-21.92
50	-34.10	-34.20	-34.40	-34.50	-34.63
75	-41.54	-41.73	-41.46	-41.64	-41.88
100	-47.01	-47.31	-47.01	-47.29	-47.63
200	-59.68	-60.46	-61.98	-62.72	-63.66
300	-68.62	-70.06	-72.82	-74.18	-75.87
400	-75.89	-78.11	-82.33	-84.38	-86.93
500	-82.34	-85.45	-91.27	-94.07	-97.54

Table 6.1b: E-field (dBμV/m) for typical UK wet ground ε_r=20, σ=15mS/m. Horizontal polarisation

Clearly, horizontally polarised emissions do suffer massive attenuation at the low ADSL frequencies and are thought not to present a really effective radiative threat. Thus, in the following we will concentrate on vertically polarised emissions.

6.6 Methodology for estimation of cumulative emissions from a typical British city

In this section a general step-by-step calculation procedure for the cumulative emissions of a typical British city is described. The methodology is quite general and flexible and the user can use their own input to produce results for their own input data. The example calculations performed below should only be interpreted as indicative due to the lack of representative input information.

Step 1. *Definition of radiating medium.*

Total area A of city: 25 km^2

Step 2. *Definition of city building makeup.*

The description of the particular city building makeup shown in Table 6.2 is thought to be representative of a typical medium-sized British city, e.g., York. It must be noted that the input parameters used below are based on reasonable estimates rather than surveyed data.

		D_i		M_{pi}	i		L_{ui}	
	p_i	density	max line	market	radiative	subscriber	Concurrent	concurrent
Makeup of radiating area	**[%]**	**lines/m^2**	**number**	**penetration**	**element**	**lines**	**usage %**	**line use**
% of bungalow houses	5.00%	0.005	6250	20.00%	drop1	1250	30.00%	375
% of terraced houses	31.00%	0.008	62000	20.00%	drop1	12400	30.00%	3720
% of semi-det. houses	41.00%	0.006	61500	20.00%	drop1	12300	30.00%	3690
% of detached houses	17.00%	0.003	12750	20.00%	drop2	2550	30.00%	765
% of 1 storey buildings	1.70%	0.002	850	20.00%	storey1	170	30.00%	51
% of 2 storey buildings	2.50%	0.002	1250	20.00%	storey2	250	30.00%	75
% of 3 storey buildings	1.00%	0.003	750	20.00%	storey3	150	30.00%	45
% of 4 storey buildings	0.50%	0.004	500	20.00%	storey4	100	30.00%	30
% of 5 storey buildings	0.20%	0.005	250	20.00%	storey5	50	30.00%	15
% of 10 storey buildings	0.10%	0.010	250	20.00%	storey10	50	30.00%	15
			146350			29270		8781

Table 6.2: Description of building makeup of radiative area (Reference City)

Step 3. *Specify reference radiating efficiency and balance at frequencies of interest.*

The radiation efficiencies quoted in Table 6.3 have been determined by NEC. They have been adapted from Section 5.

Frequency [MHz]	Balance [dB]	Pt/Pin, [%]							
		Drop1r	drop2r	storey1r	storey2r	storey3r	storey4r	Storey5r	storey10r
0.1	0	0.0412	0.0412	0.0103	0.1244	0.4518	1.072	2.039	11.79
0.2	0	0.1550	0.1550	0.0391	0.4624	1.621	3.656	6.519	26.26
0.4	0	0.5567	0.5567	0.1449	1.604	5.165	10.48	16.74	43.45
0.6	0	1.136	1.13	0.3051	3.156	9.377	17.42	25.48	49.82
0.8	0	1.853	1.853	0.5114	4.963	13.65	23.29	31.71	52.11
1.0	0	2.681	2.681	0.7592	6.926	17.54	27.86	35.85	52.72

Table 6.3a: Radiation efficiencies determined by NEC for ATU-R unbalanced metallic access cables

Frequency [MHz]	Balance [dB]	Pt/Pin, [%]							
		Drop1e	drop2e	storey1e	storey2e	storey3e	storey4e	storey5e	storey10e
0.1	0	0.006391	0.00586	0.001769	0.006632	0.012668	0.020294	0.029506	0.099175
0.2	0	0.024381	0.022364	0.006746	0.025278	0.048256	0.077249	0.112219	0.37559
0.4	0	0.091679	0.084213	0.025357	0.094806	0.180598	0.28848	0.418136	1.384081
0.6	0	0.197467	0.181758	0.054553	0.203306	0.386215	0.615251	0.889444	2.904588
0.8	0	0.339397	0.313297	0.093527	0.347179	0.65749	1.044215	1.505028	4.834889
1.0	0	0.516229	0.47834	0.141679	0.523571	0.988036	1.563975	2.246684	7.08051

Table 6.3b: Radiation efficiencies determined by NEC for ATU-C unbalanced metallic access cables

		ATU-C MDF central exchange			
Rad CF DB	Coupling [dB]	PSD [dBm/Hz]	Frequency [MHz]	Balance [dB]	Pt/Pin, % MDF drop
0	3.00	-36.5	0.1	0	0.564412
0	4.00	-36.5	0.2	0	2.043249
0	5.00	-36.5	0.4	0	6.203374
0	6.00	-36.5	0.6	0	10.18508
0	7.00	-36.5	0.8	0	13.41045
0	8.00	-36.5	1.0	0	15.92392

Table 6.3c: Radiation efficiencies determined by NEC for a single unbalanced MDF drop

The results for the single MDF drop include a coupling factor to describe the effect of the presence of other UTP pairs in the same bundle (a single bundle typically contains 50 pairs and a super-bundle tens of single bundles) on its radiation characteristics. Preliminary calculations using NEC, suggested that the presence of other pairs increases the reactance and decreases the resistance of the equivalent input impedance of a bundle of cables. This results to a reduction of the overall radiation efficiency. A 3 dB to 8 dB radiation "loss" as a function of frequency was observed in NEC simulations involving two pairs of cables. The NEC model of a cable bundle is very simplistic and the results should be treated with caution. Further work is necessary to provide a validated model for emissions from the MDF.

Step 4. *Define ATU-C and ATU-R transmission spectral mask.*

The transmit spectral mask for the Asymmetric Digital Subscriber Line is defined in the ETSI TS101-388 1998[xiv]. The ATU-C downstream transmission has -36.5dBm/Hz power spectral density (PSD) for frequencies between 138 kHz and 1.104 MHz. The ATU-R upstream transmission has a PSD of -34.5 dBm/Hz for frequencies between 138 kHz and 276 kHz. For our calculations a typical bandwidth of 10 kHz has been assumed for the power injected into the cable. Thus, for the downstream transmission (exchange to user) the injected power per 10 kHz is 2.2387 mW, and for the upstream transmission (user to exchange) is 3.5481 mW.

Step 5. *Calculate unattenuated electric field for each radiative element.*

The radiated power from each radiative element is given by

$$P_{rad} = \left.\frac{P_t}{P_{in}}\right|_{ref} P_{in}^{ADSL} balance_{ref}\, att$$

where $P_t/P_{in}|_{ref}$ is given in Table 6.4, P_{in}^{ADSL} has been determined in step 4, *att* is the attenuation per unit cable length[5] and the balance $balance_{ref}$ must be converted into a dimensionless quantity. The unattenuated electric field can then be evaluated by

$$E_1(mV/m) = 300\sqrt{P_{rad}(kW)}.$$

The results tabulated in Table 6.4a assume a cable length of 1 km, a universal balance of 50 dB and refer to downstream transmission. Also shown is the corresponding

[5] Applicable only to downstream transmission. For upstream transmission *att*=1.

attenuation at various frequencies. In Table 6.4b the unattenuated electric field for the MDF drop is given.

Freq	Att	E_1, [mV/m]							
[MHz]	[dB]	drop1e	drop2e	Storey1e	storey2e	storey3e	storey4e	storey5e	storey10e
0.1	10	3.5884E-06	3.4361E-06	1.8879E-06	3.6555E-06	5.0521E-06	6.3945E-06	7.7104E-06	1.4136E-05
0.2	12	5.5673E-06	5.3321E-06	2.9285E-06	5.6688E-06	7.8324E-06	9.9099E-06	1.1944E-05	2.1851E-05
0.4	14	8.5754E-06	8.2188E-06	4.5099E-06	8.7205E-06	1.2036E-05	1.5212E-05	1.8314E-05	3.3320E-05
0.6	16	9.9970E-06	9.5911E-06	5.2545E-06	1.0144E-05	1.3981E-05	1.7646E-05	2.1217E-05	3.8341E-05
0.8	18	1.0411E-05	1.0002E-05	5.4650E-06	1.0529E-05	1.4490E-05	1.8261E-05	2.1923E-05	3.9293E-05
1.0	20	1.0199E-05	9.8172E-06	5.3429E-06	1.0271E-05	1.4109E-05	1.7752E-05	2.1276E-05	3.7771E-05

Table 6.4a: Unattenuated electric field E_1 for downstream transmission (exchange to remote user)

Freq	E1, [mV/m]
[MHz]	MDF drop
0.1	7.5495E-04
0.2	1.2802E-03
0.4	1.9881E-03
0.6	2.2704E-03
0.8	2.3219E-03
1.0	2.2550E-03

Table 6.4b: Unattenuated electric field E_1 for downstream transmission (MDF drop)

Results for upstream transmission are shown in Table 6.4c. Similarly, a universal balance value of 50 dB has been used for our calculations.

Freq [MHz]	Att [dB]	E_1, [mV/m]							
		drop1r	drop2r	storey1r	storey2r	storey3r	storey4r	storey5r	storey10r
0.1	0	3.6300E-05	6.9715E-06	1.8139E-05	6.3052E-05	1.2012E-04	1.8504E-04	2.5522E-04	6.1382E-04
0.2	0	7.0371E-05	1.7871E-05	3.5371E-05	1.2152E-04	2.2753E-04	3.4169E-04	4.5627E-04	9.1578E-04
0.4	0	1.3334E-04	4.6207E-05	6.8037E-05	2.2637E-04	4.0615E-04	5.7864E-04	7.3118E-04	1.1779E-03
0.6	0	1.9053E-04	8.0357E-05	9.8708E-05	3.1750E-04	5.4724E-04	7.4585E-04	9.0218E-04	1.2614E-03
0.8	0	2.4330E-04	1.1994E-04	1.2780E-04	3.9813E-04	6.6032E-04	8.6257E-04	1.0064E-03	1.2900E-03
1.0	0	2.9261E-04	1.6483E-04	1.5571E-04	4.7029E-04	7.4857E-04	9.4329E-04	1.0700E-03	1.2976E-03

Table 6.4c: Unattenuated electric field E_1 for upstream transmission (remote user to exchange)

Step 6. *Calculate the appropriate electric field correction factor.*

In order to calculate to field due to the various radiating mechanisms the ITU-R P368 reference electric field values listed in Table 2 need to be corrected by a correction factor $CF(dB)=20\log(E_1(mV/m)/300)$. The correction factors for the ATU-C and ATU-R transmissions are given in Tables 6.5a, 6.5b and 6.5c respectively.

Freq	ATU-R CF, [dB]							
[MHz]	drop1e	Drop2e	storey1e	storey2e	storey3e	storey4e	storey5e	storey10e
0.1	-1.5844E+02	-1.5882E+02	-1.6402E+02	-1.5828E+02	-1.5547E+02	-1.5343E+02	-1.5180E+02	-1.4654E+02
0.2	-1.5463E+02	-1.5500E+02	-1.6021E+02	-1.5447E+02	-1.5166E+02	-1.4962E+02	-1.4800E+02	-1.4275E+02
0.4	-1.5088E+02	-1.5125E+02	-1.5646E+02	-1.5073E+02	-1.4793E+02	-1.4590E+02	-1.4429E+02	-1.3909E+02
0.6	-1.4955E+02	-1.4991E+02	-1.5513E+02	-1.4942E+02	-1.4663E+02	-1.4461E+02	-1.4301E+02	-1.3787E+02
0.8	-1.4919E+02	-1.4954E+02	-1.5479E+02	-1.4909E+02	-1.4632E+02	-1.4431E+02	-1.4272E+02	-1.3766E+02
1.0	-1.4937E+02	-1.4970E+02	-1.5499E+02	-1.4931E+02	-1.4655E+02	-1.4456E+02	-1.4298E+02	-1.3800E+02

Table 6.5a: Electric field correction factor for downstream transmission

Freq	CF, [dB]
[MHz]	MDF drop
0.1	-1.1198E+02
0.2	-1.0740E+02
0.4	-1.0357E+02
0.6	-1.0242E+02
0.8	-1.0223E+02
1.0	-1.0248E+02

Table 6.5b: Electric field correction factor for MDF downstream transmission

Freq	ATU-C CF, [dB]							
[MHz]	drop1r	Drop2r	storey1r	storey2r	storey3r	storey4r	storey5r	storey10r
0.1	-1.3834E+02	-1.5268E+02	-1.4437E+02	-1.3355E+02	-1.2795E+02	-1.2420E+02	-1.2140E+02	-1.1378E+02
0.2	-1.3259E+02	-1.4450E+02	-1.3857E+02	-1.2785E+02	-1.2240E+02	-1.1887E+02	-1.1636E+02	-1.1031E+02
0.4	-1.2704E+02	-1.3625E+02	-1.3289E+02	-1.2245E+02	-1.1737E+02	-1.1429E+02	-1.1226E+02	-1.0812E+02
0.6	-1.2394E+02	-1.3144E+02	-1.2966E+02	-1.1951E+02	-1.1478E+02	-1.1209E+02	-1.1044E+02	-1.0753E+02
0.8	-1.2182E+02	-1.2796E+02	-1.2741E+02	-1.1754E+02	-1.1315E+02	-1.1083E+02	-1.0949E+02	-1.0733E+02
1.0	-1.2022E+02	-1.2520E+02	-1.2570E+02	-1.1610E+02	-1.1206E+02	-1.1005E+02	-1.0895E+02	-1.0728E+02

Table 6.5c: Electric field correction factor for upstream transmission

Step 7. *Evaluate the total interference electric field.*

Once the correction factors have been determined, the electric field strength due to an individual radiating element as a function of distance can be calculated. The cumulative effect of numerous radiating elements in either downstream or upstream transmission can be readily evaluated using the equation of section 6.4.

6.7 Test cases and results

In this section results for cities of various sizes and percentages of market penetration are reported. Results are reported both in graphical (Appendix 5) and tabular form (Appendix 6) for ATU-C and MDF transmissions for the following cases:

Case 1a. City, area *25 km²*, balance *50 dB*, percentage of market penetration *20%*, concurrent line use percentage *30%*.

1b. City, area *25 km²*, balance *30 dB*, percentage of market penetration *20%*, concurrent line use percentage *30%*.

Case 2a. City, area *100 km²*, balance *50 dB*, percent market penetration *20%*, concurrent line use percentage *30%*.

2b. City, area *100 km²*, balance *30 dB*, percent market penetration *20%*, concurrent line use percentage *30%*.

The case studies are designed in such a way that the effects of poorly balanced cables and percent of market penetration can be assessed. Case 1 may be thought to represent a medium-sized city such as York, whereas case 2 is representative of a large city such as Leeds. The effect of poorly balanced cables on radiative emissions is expected to be a quite important issue. Although there will be always a percentage of poorly balanced lines, for widespread deployment of the ADSL technology, it is the overall average that matters in the calculations. In the calculations balance values of 50 dB and 30 dB have been assumed, representing an absolute best and a typical case scenario, respectively. The results shown in Appendix 5 and 6 apply to the ATU-R and MDF transmission modes. Results for the ATU-C transmission mode are not shown because they are well below the field values resulting from the MDF transmission. Nevertheless, these can be seen in the active spreadsheet, which accompanies this report, instructions for which are contained in Appendix 8.

Careful observation of the reported results reveals the dramatic effect of poorly balanced cables on cumulative radiation levels. Radiation levels increase consistently by a margin in dB equal to the balance difference in dB. Thus, for arbitrary values of balance one would simply add the difference from the quoted results in section 5. For example, the electric field strength due to the city model 2a at distance 100 km away from the city centre, at a frequency of 1 MHz and an average balance of 40 dB would be -21.6dBμV/m+(50 dB-40 dB)=-11.6dBμV/m.

The effect of market penetration can also be evaluated in a straightforward manner, by adjusting the quoted values by a factor equal to 10log(new %/quoted %). If the technology was applied to 50% of the potential market, the electric field at all frequencies and distances for all cases would increase by a factor 10log(50/20)=4 dB.

The dependence of the electric field with distance is approximately -20 dB/decade for frequencies between 100 kHz and 400 kHz, -25 dB/decade for frequencies between 600 and 800 kHz and -30 dB/decade at 1 MHz for distances up to approximately the distance d_{max} defined in section 2. This trend is independent of balance and percentage of market penetration. Important results at a fixed distance 10 km away from the city centre are usefully summarised in Tables 6.6a and 6.6b.

Freq [MHz]	**Case 1**		**Case 2**	
	1a	1b	2a	2b
0.1	-7.3	12.7	-1.3	18.7
0.2	-2.3	17.7	3.8	23.8

Table 6.6a: Emission electric field resulting from cumulative ATU-R upstream transmissions at distance 10 km away from the city centre

Freq [MHz]	**Case 1**		**Case 2**	
	1a	1b	2a	2b
0.4	5.0	25.0	11.1	31.1
0.6	5.8	25.8	11.8	31.8
0.8	5.5	25.5	11.5	31.5
1.0	4.6	24.6	10.7	30.7

Table 6.6b: Emission electric field resulting from cumulative MDF downstream transmissions at distance 10 km away from the city centre

As expected, the city models with the typical balance of 30 dB produce significant electric field values. These values need to be compared with the electric field noise floor (atmospheric, galactic, man-made).

6.8 The effect of ADSL technology on the electric field noise floor and radio services

In order to determine whether cumulative ADSL emissions are likely to change the level of the radio noise floor use has been made of the ITU-R P372 recommendation to determine the atmospheric, galactic and man-made noise per Hz of bandwidth at frequencies between 30 kHz and 30 MHz. Subsequently, assuming a 10 kHz receiver bandwidth the noise field strength can be evaluated. The median noise field strength as a function of frequency and season at 12 noon for a residential location in central England is depicted in Figure 6.1. The noise field has been evaluated at 12 noon, because it then takes its minimum value. For the ADSL band, relevant mean noise field values can be seen in Table 6.7.

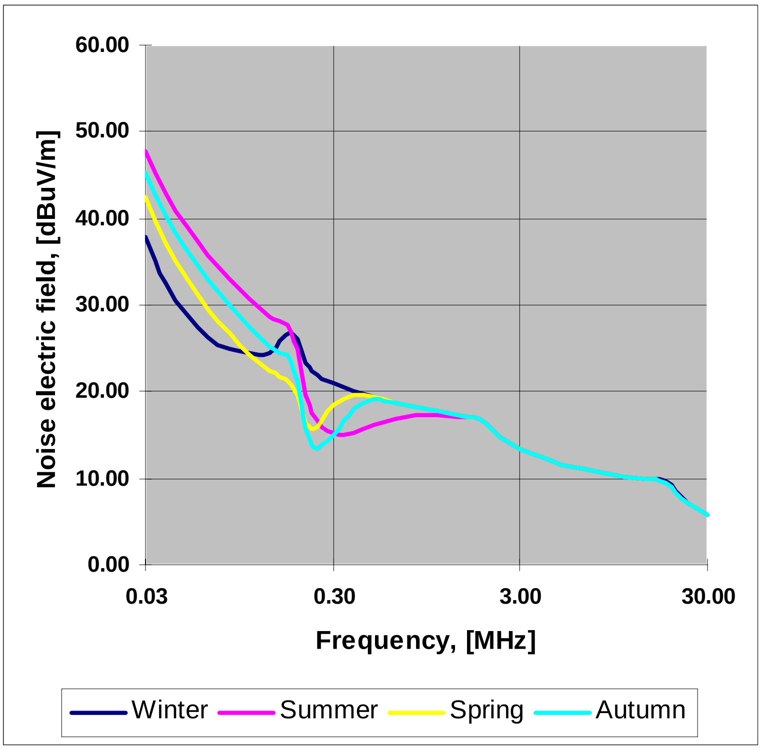


Figure 6.1: Graph of the typical median noise electric field at a receiver with noise bandwidth 10 kHz at noon

Freq [MHz]	**Noise electric field, [dBμV/m]**			
	Winter	Spring	Summer	Autumn
0.1	26.66	20.66	26.86	23.26
0.2	22.48	15.78	17.58	13.78
0.4	20.00	19.70	15.30	18.10
0.6	18.72	18.72	16.82	18.72
0.8	17.72	17.72	17.32	17.72
1.0	16.96	16.96	16.96	16.96

Table 6.7: Median noise electric field at a receiver with noise bandwidth 10 kHz for a residential location at central England (Latitude 54.5N, Longitude 1W)

Direct comparison of the ADSL emission values tabulated in Tables 6.6a and 6.6b and the noise electric field values in Table 6.7, do not suggest any significant changes in the median levels of the established noise floor for the well balanced city models[6]. Nevertheless, for the less well balanced city models and at distances less than 3km the ADSL emission fields are predicted to take much higher values. For these cases the established radio noise floor may increase by an appreciable margin depending upon frequency and mode of operation, i.e., downstream or upstream transmission. In the ATU-R context and assuming the present spectral mask characteristics, an average increase of 10 to 20dB should be expected at short distances from the city centre. In the MDF context, an average increase of 15 to 30dB should be expected. It should be remembered that these comparisons have been made against the typical scenario in which cable balance is 30dB. For the optimistically balanced city model (balance of 50dB or better) no likely change in the median levels of the radio noise floor is expected for distances greater than 5km away from the MDF. Obviously, for distances in excess of 25km away from the effective radiation city centre, the ADSL emissions are well below the established radio noise floor.

To assess the effect of the widespread application of the ADSL technology on radio broadcasting services, knowledge of the magnitude of field strength needed for good quality reception of radio broadcasts in the presence of overall noise is required. According to Griffiths[xv] for good quality analogue reception average electric field strength values of 85dBμV/m, 73dBμV/m and 60dBμV/m are needed in the presence

[6] It should be recalled that ADSL-induced noise is Gaussian in nature.

of receiver, atmospheric, galactic and man-made noise, for typical city/industrial, city/residential and rural/residential areas. These field values are thought to be adequate to achieve at least a 26dB signal-to-noise ratio (SNR) at the receiver input. Thus, the noise floor corresponding to each of these areas is around 59dBμV/m, 47dBμV/m and 34dBμV/m, respectively. For the city/residential typical case scenario (average city cable balance 30dB) and for distances greater than 2km from the MDF, the predicted ADSL emission field values are at the same level or below the corresponding noise floor. Moreover, the ADSL induced noise field is Gaussian in nature and this should be taken into account when assessing its effect on radio-based services. For some services protection of the median noise floor should be sufficient, whereas for others with trained, motivated operators, useful intelligence can be obtained from signals that are apparently too weak when compared with the ITU-R P.372 median noise floor. The non-uniform nature of noise allows for information to be distinguished between the noise peaks and with full duplex systems the message can be repeated if necessary. In other words, when communication or interception is important enough, useful results can be had even if the useful transmitted signal lies below the established median noise floor. In contrast, Gaussian noise of the same apparent *rms* value will have a much more disruptive effect.

7 INVESTIGATION OF PROPAGATION OF CUMULATIVE VDSL EMISSIONS

7.1 Groundwave propagation of cumulative VDSL emissions

Several telecommunications companies have begun to exploit their existing cable networks by using new technologies capable of transmitting digital data at rates up to 30 Mbit/s. Nevertheless, the deployment of technologies such as xDSL, PLT and Home LAN, pose a real potential threat of pollution to much of the radio spectrum from 9 kHz to 200 MHz. The potential electromagnetic pollution problem is manifesting itself by the simultaneous transmission of radiation by the ground and sky wave. For frequencies up to at least 30 MHz both sky and ground wave propagation is applicable, with the ground wave tending to dominate at the lower frequencies, and the sky wave becoming increasingly important for frequencies above about 3 MHz. For the VDSL technology which potentially utilizes frequencies between 30 kHz and 30 MHz for digital data transmission the ground wave is a potentially serious electromagnetic threat. In the following, the detailed and comprehensive methodology introduced originally in section 6, is utilised to assess the cumulative emissions resulting from the widespread application of the VDSL technology.

7.1.1 Electric field strength calculations (groundwave)

The theory of ground wave propagation in the context of calculating cumulative emissions has been reviewed in detail in section 6. Once more, the PC version of the well known ITU GRWAVE software was used to estimate the electric field strength as a function of distance for the VDSL frequency band. The tabulated values assume a short monopole antenna having an unattenuated electric field of 300 mV/m. Because horizontally polarised waves suffer massive attenuation, they do not present a radiative threat.

The results were corrected by applying the appropriate correction factor to match the radiative properties of more complex structures associated with the metallic copper access network. The calculations for the complex structures have been carried out for upstream and downstream transmission, i.e., from the VDSL Network Termination (NT) to the VDSL Line Termination (LT) and vice versa. This was accomplished by exciting the radiating configurations at different points. A detailed description of the modelling assumptions, geometry and radiation patterns of complex structures can be found in section 5. It must be noted that over much of the VDSL band, the radiation patterns of individual radiative elements become highly directive towards the sky especially as frequency increases. The clear implication is an ever increasing space-wave contribution resulting in a potential increase of the radio noise floor at high altitudes above the Earth's surface.

Distance (km)	1 MHz	2 MHz	4 MHz	6 MHz	8 MHz	10 MHz
1	109.22	108.46	105.76	102.18	98.52	95.26
10	87.68	82.84	70.43	62.35	57.41	53.93
25	77.39	67.63	52.72	45.42	40.70	37.29
50	67.76	53.55	39.40	32.26	27.31	23.91
75	60.96	45.11	31.25	23.81	18.79	15.06
100	55.41	38.95	24.90	17.16	11.87	7.91
200	39.43	21.94	5.87	-3.50	-10.16	-15.30
300	28.02	8.69	-10.13	-21.50	-29.76	-36.28
400	18.19	-3.56	-25.42	-38.90	-48.84	-56.77
500	8.96	-15.45	-40.43	-56.04	-67.66	-77.00

Table 7.1: Vertically polarised surface wave E-field(dBμV/m) for typical UK wet ground ε_r=20, σ=15mS/m

Other important factors which need to be considered in the context of ingress and egress issues of metallic access cables are the far-end (FEXT) and near-end (NEXT) crosstalk and balance. The cables used in the access networks are unshielded twisted pairs (UTP) of various gauges. Most pairs are twisted to improve their longitudinal balance as well as to reduce crosstalk, emissions and pickup. The balance of a UTP decreases generally with frequency, although resonant features may be present and is generally better than 30 dB for frequencies above 1 MHz and up to 10 MHz[xiii]. Nevertheless, the balance varies from pair to pair and will depend on many factors such as cable type, its quality and age, the installation configuration and external factors such as humidity and condensation. To verify this, independent emission tests from UTP cables were performed at Whyteleafe laboratory. These results for balanced and unbalanced cables have been reported in section 4. For our practical calculations, an average difference between balanced and unbalanced cables of the order of 30 dB has been assumed.

7.1.2 Calculation strategy of cumulative emissions

The same strategy as described in section 6.4 for ADSL is applied. However for VDSL the exchange MDF drop does not need to be taken into account. This is because the VDSL ONU (Optical Network Unit) will always be sited on the user side of the exchange. The ONU is the transducer from optical fibre to copper twisted pair.

7.1.3 Emissions from a typical British city

In this section the general step-by-step calculation procedure introduced in section 6 for the determination of cumulative ADSL emissions of a typical British city will be applied. The example calculations performed below should be interpreted as only indicative due to the lack of accurate input information.

Step 1. *Definition of radiating medium.*

Total area A of area:e.g. 2.5 km^2 corresponding to the total area of buildings subscribed to the relevant xDSL technology.

Step 2. *Definition of city building makeup.*

The description of the particular city building makeup is similar to that given in section 6. Once more, it is emphasized that the quoted values should be only considered as the author's best personal estimate in order to facilitate the utility of the proposed methodology.

Step 3. *Specify reference radiating efficiency and balance at frequencies of interest.*

The radiation efficiencies quoted in Tables 7.2a and 7.2b have been determined by NEC.

Freq.	Balance	Pt/Pin, [%]							
[MHz]	[dB]	drop1r	drop2r	storey1r	storey2r	storey3r	storey4r	storey5r	storey10r
1	30	2.68116	0.85080	0.75924	6.92607	17.54771	27.86436	35.85473	52.72728
2	30	7.79688	5.66725	2.57620	16.38694	29.99970	38.24285	42.96846	48.86609
4	30	20.5874	26.3010	8.46203	28.91718	38.23302	41.39272	41.95370	34.58350
6	30	38.9112	43.6965	16.20190	36.40732	40.53034	39.21421	36.01925	30.90542
8	30	57.1076	48.2379	24.38516	41.00603	39.49195	33.76300	28.81225	51.94933
10	30	52.7286	45.5674	31.99089	42.99900	35.50719	27.88012	25.62666	57.11920

Table 7.2a: Radiation efficiencies determined by NEC for NT-LT unbalanced metallic access cables

Freq.	Balance	Pt/Pin, [%]							
[MHz]	[dB]	drop1e	drop2e	storey1e	storey2e	storey3e	storey4e	storey5e	storey10e
1	30	0.51623	0.47834	0.14168	0.52357	0.98804	1.56398	2.24668	7.08051
2	30	1.92785	1.84391	0.50659	1.81902	3.35652	5.19277	7.28539	20.16798
4	30	8.63073	9.85512	1.78793	5.87761	10.13356	14.66348	19.22770	34.92622
6	30	30.28500	42.14234	3.77430	10.99157	17.38913	23.16276	27.83732	26.50616
8	30	55.47064	36.72425	6.46517	16.34884	23.54293	28.46209	30.03678	57.73832
10	30	42.96326	26.60872	9.79758	21.38140	27.91095	29.65440	26.28118	55.11821

Table 7.2b: Radiation efficiencies determined by NEC for LT-NT unbalanced metallic access cables

Step 4. *Define transmit LT-NT and NT-LT spectral mask.*

The transmit spectral mask for the Very-high Digital Subscriber Line is defined in the ETSI TS101-270-1 1999[xvii]. The probable linecode is a discrete multitone scheme with each carrier quadrature amplitude modulated. The proposed duplexing method for VDSL is time domain duplexing (TDD) with a frequency of 1kHz and consequently the entire allocated spectrum can be concurrently used for the LT-NT downstream and NT-LT upstream transmissions. These have a similar power spectral density, i.e., -60dBm/Hz for frequencies between 1.1MHz and 10MHz. (The VDSL spectral specification extends actually from 100kHz to 30MHz, however serious crosstalk concerns have suggested placing the VDSL spectrum above the ADSL spectrum.) Thus, in this report only the frequency range between 1.1 and 10MHz is considered. For our calculations a typical bandwidth of 10kHz has been assumed for the power injected into the cable. Therefore, for both upstream and downstream transmissions the injected power per 10kHz is 0.01mW.

Step 5. *Calculate unattenuated electric field for each radiative element.*

The radiated power from each radiative element is given by

$$P_{rad} = \left.\frac{P_t}{P_{in}}\right|_{ref} P_{in}^{VDSL} balance_{ref}\, att$$

where $P_t/P_{in}|_{ref}$ is given in Tables 7.2a, 7.2b, P_{in}^{VDSL} has been determined in step 4, *att* is the cable loss and the balance $balance_{ref}$ must be converted into a dimensionless quantity. The unattenuated electric field can then be evaluated by

$$E_1(mV/m) = 300\sqrt{P_{rad}(kW)}.$$

The results tabulated in Tables 7.3a and 7.3b assume a balance of 30dB and refer to downstream and upstream transmission, respectively.

Freq.	E1, [mV/m]							
[MHz]	drop1r	drop2r	storey1r	storey2r	storey3r	storey4r	storey5r	storey10r
1.0	1.5534E-04	8.7506E-05	8.2663E-05	2.4967E-04	3.9740E-04	5.0078E-04	5.6806E-04	6.8887E-04
2.0	2.6490E-04	2.2584E-04	1.5227E-04	3.8403E-04	5.1961E-04	5.8667E-04	6.2187E-04	6.6317E-04
4.0	4.3045E-04	4.8653E-04	2.7597E-04	5.1015E-04	5.8660E-04	6.1036E-04	6.1448E-04	5.5790E-04
6.0	5.9178E-04	6.2711E-04	3.8186E-04	5.7242E-04	6.0396E-04	5.9408E-04	5.6936E-04	5.2740E-04
8.0	7.1692E-04	6.5889E-04	4.6847E-04	6.0750E-04	5.9618E-04	5.5124E-04	5.0923E-04	6.8377E-04
10.0	6.8888E-04	6.4040E-04	5.3658E-04	6.2209E-04	5.6530E-04	5.0092E-04	4.8025E-04	7.1699E-04

Table 7.3a: Unattenuated electric field E_1 for upstream transmission (LT to NT)

Freq.	E1, [mV/m]							
[MHz]	drop1e	drop2e	storey1e	storey2e	storey3e	storey4e	storey5e	storey10e
1.0	3.4162E-05	3.2884E-05	1.7897E-05	3.4404E-05	4.7262E-05	5.9462E-05	7.1268E-05	1.2652E-04
2.0	5.0952E-05	4.9830E-05	2.6119E-05	4.9493E-05	6.7230E-05	8.3622E-05	9.9048E-05	1.6480E-04
4.0	7.5014E-05	8.0159E-05	3.4143E-05	6.1904E-05	8.1283E-05	9.7778E-05	1.1197E-04	1.5090E-04
6.0	9.2840E-05	1.0952E-04	3.2775E-05	5.5931E-05	7.0349E-05	8.1193E-05	8.9009E-05	8.6855E-05
8.0	1.0572E-04	8.6020E-05	3.6092E-05	5.7394E-05	6.8873E-05	7.5728E-05	7.7794E-05	1.0786E-04
10.0	7.8283E-05	6.1607E-05	3.7384E-05	5.5225E-05	6.3097E-05	6.5038E-05	6.1227E-05	8.8668E-05

Table 7.3b: Unattenuated electric field E_1 for downstream transmission (LT to NT)

Step 6. *Calculate the appropriate electric field correction factor.*

In order to calculate to field due to the various radiating mechanisms the ITU-R P368 reference electric field values listed in Tables 7.3a and 7.3b need to be corrected by a correction factor $CF(dB)=20\log(E_1(mV/m)/300)$. The correction factors for the LT-NT and NT-LT transmissions are given in Tables 7.4a and 7.4b, respectively.

NT-LT CF, [dB]							
drop1r	**drop2r**	**storey1r**	**storey2r**	**storey3r**	**storey4r**	**storey5r**	**storey10r**
-1.2572E+02	-1.3070E+02	-1.3120E+02	-1.2160E+02	-1.1756E+02	-1.1555E+02	-1.1445E+02	-1.1278E+02
-1.2108E+02	-1.2247E+02	-1.2589E+02	-1.1786E+02	-1.1523E+02	-1.1417E+02	-1.1367E+02	-1.1311E+02
-1.1686E+02	-1.1580E+02	-1.2073E+02	-1.1539E+02	-1.1418E+02	-1.1383E+02	-1.1377E+02	-1.1461E+02
-1.1410E+02	-1.1360E+02	-1.1790E+02	-1.1439E+02	-1.1392E+02	-1.1407E+02	-1.1443E+02	-1.1510E+02
-1.1243E+02	-1.1317E+02	-1.1613E+02	-1.1387E+02	-1.1403E+02	-1.1472E+02	-1.1540E+02	-1.1284E+02
-1.1278E+02	-1.1341E+02	-1.1495E+02	-1.1367E+02	-1.1450E+02	-1.1555E+02	-1.1591E+02	-1.1243E+02

Table 7.4a: Electric field correction factor for downstream transmission

LT-NT CF, [dB]							
drop1e	**drop2e**	**storey1e**	**storey2e**	**storey3e**	**storey4e**	**storey5e**	**storey10e**
-1.3887E+02	-1.3920E+02	-1.4449E+02	-1.3881E+02	-1.3605E+02	-1.3406E+02	-1.3248E+02	-1.2750E+02
-1.3540E+02	-1.3559E+02	-1.4120E+02	-1.3565E+02	-1.3299E+02	-1.3110E+02	-1.2963E+02	-1.2520E+02
-1.3204E+02	-1.3146E+02	-1.3888E+02	-1.3371E+02	-1.3134E+02	-1.2974E+02	-1.2856E+02	-1.2597E+02
-1.3019E+02	-1.2875E+02	-1.3923E+02	-1.3459E+02	-1.3260E+02	-1.3135E+02	-1.3055E+02	-1.3077E+02
-1.2906E+02	-1.3085E+02	-1.3839E+02	-1.3437E+02	-1.3278E+02	-1.3196E+02	-1.3172E+02	-1.2889E+02
-1.3167E+02	-1.3375E+02	-1.3809E+02	-1.3470E+02	-1.3354E+02	-1.3328E+02	-1.3380E+02	-1.3059E+02

Table 7.4b: Electric field correction factor for upstream transmission

Step 7. *Evaluate the total interference electric field.*

Once the correction factors have been determined, the electric field strength due to an individual radiating element as a function of distance can been calculated. The cumulative effect of numerous radiating elements in either downstrean or upstream transmission can be readily evaluated using the equation of section 7.1.2.

7.1.4 Test cases and results

In this section results for cities of various sizes and percentages of market penetration are reported. Results are reported both in graphical and tabular form for LT-NT and NT-LT transmissions for the following cases:

Case 1a. City, area *2.5 km²*, balance *30 dB*, percentage of market penetration *20%*, concurrent line use percentage *30%*.

1b. City, area *2.5 km²*, balance *20 dB*, percentage of market penetration *20%*, concurrent line use percentage *30%*.

Case 2a. City, area *10 km²*, balance *30 dB*, percent market penetration *20%*, concurrent line use percentage *30%*.

2b. City, area *10 km²*, balance *20 dB*, percent market penetration *20%*, concurrent line use percentage *30%*.

The case studies are designed in such a way that the effects of poorly balanced cables can be assessed. Case 1 may be thought to represent a fractional area of a medium-sized city such as York, whereas case 2 is representative of a fractional area of a large city such as Leeds. The effect of poorly balanced cables on radiative emissions is expected to be a quite important issue. Although there will be always a percentage of poorly balanced lines, for widespread application of the VDSL technology, it is the overall average that matters in the calculations. In the calculations balance values of 30 dB and 20 dB have been assumed, representing an optimistic and a typical scenario, respectively.

Careful observation of the reported results in Appendix 7, reveals the dramatic effect of poorly balanced cables on cumulative radiation levels. Radiation levels increase consistently by a margin in dB equal to the balance difference in dB. Thus, for arbitrary values of balance one would simply add the difference from the quoted results. For example, the downstream electric field strength due to the city model 2b at distance 25 km away from the city centre, at a frequency of 2 MHz and an average balance of 25 dB would be -10.93 dBμV/m + (20 dB - 25 dB) = -15.93 dBμV/m.

The effect of market penetration can be also evaluated in a straightforward manner, by adjusting the quoted values by a factor equal to 10log(new %/quoted %). If for example the technology was applied to 50% of the potential market, then the adjustment factor would be 10log(50/20)=4 dB.

The dependence of the electric field with distance is approximately -30 dB/decade for frequencies around 1 MHz and approaches to -45 dB/decade for frequencies between 2 and 10 MHz for distances up to 100 km. This trend is independent of balance and percent of market penetration. Important results at a fixed distance 10 km away from the city centre are usefully summarized in Tables 7.5a and 7.5b.

Freq. [MHz]	**Case 1**		**Case 2**	
	1a	**1b**	**2a**	**2b**
1	-10.10	-0.10	-4.07	+5.93
2	-10.45	-0.45	-4.43	+5.57
4	-18.61	-8.61	-12.59	-2.59
6	-24.05	-14.05	-18.03	-8.03
8	-27.45	-17.45	-21.43	-11.43
10	-31.26	-21.26	-25.24	-15.24

Table 7.5a: Emission electric field resulting from cumulative NT-LT upstream transmissions at distance 10 km away from the city centre

Freq. [MHz]	**Case 1**		**Case 2**	
	1a	**1b**	**2a**	**2b**
1	-13.58	-3.58	-7.56	+2.44
2	-11.75	-1.75	-5.72	+4.28
4	-17.93	-7.93	-11.91	-1.91
6	-23.84	-13.84	-17.82	-7.82
8	-28.31	-18.31	-22.29	-12.29
10	-31.96	-21.96	-25.94	-15.94

Table 7.5b: Emission electric field resulting from cumulative LT-NT downstream transmissions at distance 10 km away from the city centre

As expected, the city models with the poor balance of 20 dB produce significant electric field values at short distances from the effective radiation centre. These values need to be compared with the electric field noise floor (atmospheric, galactic, man-made).

7.1.5 The effect of VDSL technology on the electric field noise floor and radio services

In order to determine whether cumulative VDSL emissions are likely to change the level of the radio noise floor use of the ITU-R P.372 has been made to determine the atmospheric, galactic and man-made noise per Hz of bandwidth at frequencies between 30 kHz and 30 MHz. Subsequently, assuming a 10 kHz receiver bandwidth the noise field strength can be evaluated. The noise field strength as a function of frequency and season at 12 noon for a rural[7] location at central England is depicted in Figure 7.1. The noise field has been evaluated at 12 noon, because it takes then its minimum value.

[7] Noise values for residential areas can be somewhat higher but here we are considering a worse case scenario.

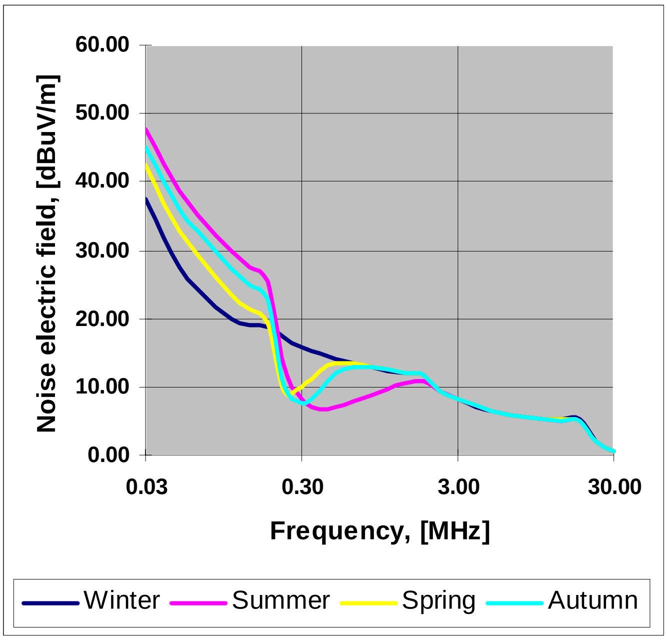


Figure 7.1: Graph of typical noise electric field at a receiver with noise bandwidth 10 kHz at noon

Especially for the VDSL band relevant noise field values can be seen in Table 7.6.

Freq. [MHz]	**Noise electric field, [dBμV/m]**			
	Winter	**Spring**	**Summer**	**Autumn**
1	11.76	11.76	10.76	11.76
2	9.38	9.48	9.48	9.48
3	8.10	8.10	8.10	8.10
4	7.10	7.20	7.20	7.20
5	6.44	6.44	6.54	6.44
6	5.82	5.92	5.92	5.92
7	5.46	5.46	5.56	5.56
8	5.22	5.22	5.32	5.22
9	5.14	5.14	5.04	5.04
10	5.26	5.06	4.86	5.06

Table 7.6: Noise electric field at a receiver with noise bandwidth 10 kHz for a rural location at central England (Latitude 54.5N, Longitude 1W)

Direct comparison of the VDSL emission values tabulated in section 7.1.4 and the noise electric field values in Table 7.6, do not suggest any significant changes in the levels of the established noise floor for all frequencies and receivers located at distances greater than 10km away from the effective emission centre. Nevertheless, at shorter distances the VDSL emissions are likely to have much higher values, i.e., at a distance only 1km away from the effective city centre, field strengths 25 to 35dB above those quoted at a distance 10km are expected. In this instance the established radio noise floor may increase by a respectable oscillating margin depending upon frequency and mode of operation. (The oscillation between a high and a low value is due to the fact that the system is time division duplexed.) In the NT-LT context and assuming the present spectral mask characteristics, an average increase of 15 to 20dB above the established radio noise floor could be expected at short distances away from densely populated areas and especially for the lower frequencies. In the LT-NT context, a more modest average increase of 5 to 10dB could be expected. It should be noted that these comparisons have been made against the typical scenario for which the cable balance is 20dB. For the well-balanced city model (balance of 30dB) likely change in the levels of the radio noise floor is expected only close to densely populated areas where widespread application of the VDSL service exists. For distances 10km away from the effective radiation centre, the predicted VDSL emissions are expected to lie well below the established radio noise floor.

To assess the effect of the widespread application of the VDSL technology on radio-based services, knowledge of the magnitude of field strength needed for good quality reception of radio transmissions in the presence of overall noise is required. For good quality HF radio service reception, average electric field strength values of 65dBμV/m, 57dBμV/m and 50dBμV/m are needed in the presence of receiver, for typical city/industrial, city/residential and rural/residential areas. These field values are thought to be adequate to achieve at least a 30dB signal-to-noise ratio (SNR) at the receiver. Thus, for selected sensitive areas where an increase to the established noise floor is expected, radio broadcasting, amateur radio and government services may be affected in an unfavourable way.

Military mobiles are especially vulnerable since they have to work with very low field strengths of wanted signal. As an example, very robust waveforms have just been developed and standardised within NATO for low data rates capable of operating at some 8dB below the ambient noise in a 3kHz receiver bandwidth in the HF band. Furthermore, data rates of 9.6kbps and above are becoming standardised within the 3kHz bandwidths normally available at HF and these demand at least 33dB SNR in order to give any availability at all (these services make use of the ground-wave mode of propagation). It should be noted that for military communications all parts of the HF frequency band are important, but frequencies around 3MHz to 5MHz which are subject to VDSL interference are essential for short/medium length communications paths at night when other HF frequencies will not work.

Other services that may be unfavourably affected include aeronautical radionavigation, mobile communications and data links operated in the close vicinity of densely populated areas in which VDSL service has been extensively deployed.

7.2 Skywave propagation of cumulative VDSL emissions

ADSL technology in the UK is currently undergoing trials in Hull and North London. In North America the technology is already deployed and exists as two types[xvi] CAP (Carrierless Amplitude Phase) and DMT (Discrete Multitone). The following analysis assumes that DMT is to be used. DMT has discrete tones at 4.3125kHz intervals. ADSL does not use tones above #255 (f=1099.6875kHz). VDSL[xvii] allows tone usage above #255. No upper tone limit is defined, however, the spectral masks for VDSL extend up to 30MHz. VDSL is allowed to use the ADSL frequency range but at a lower PSD(Power Spectral Density) than is allowed for ADSL. The VDSL general reference model[xvii] is shown in Figure 7.2.

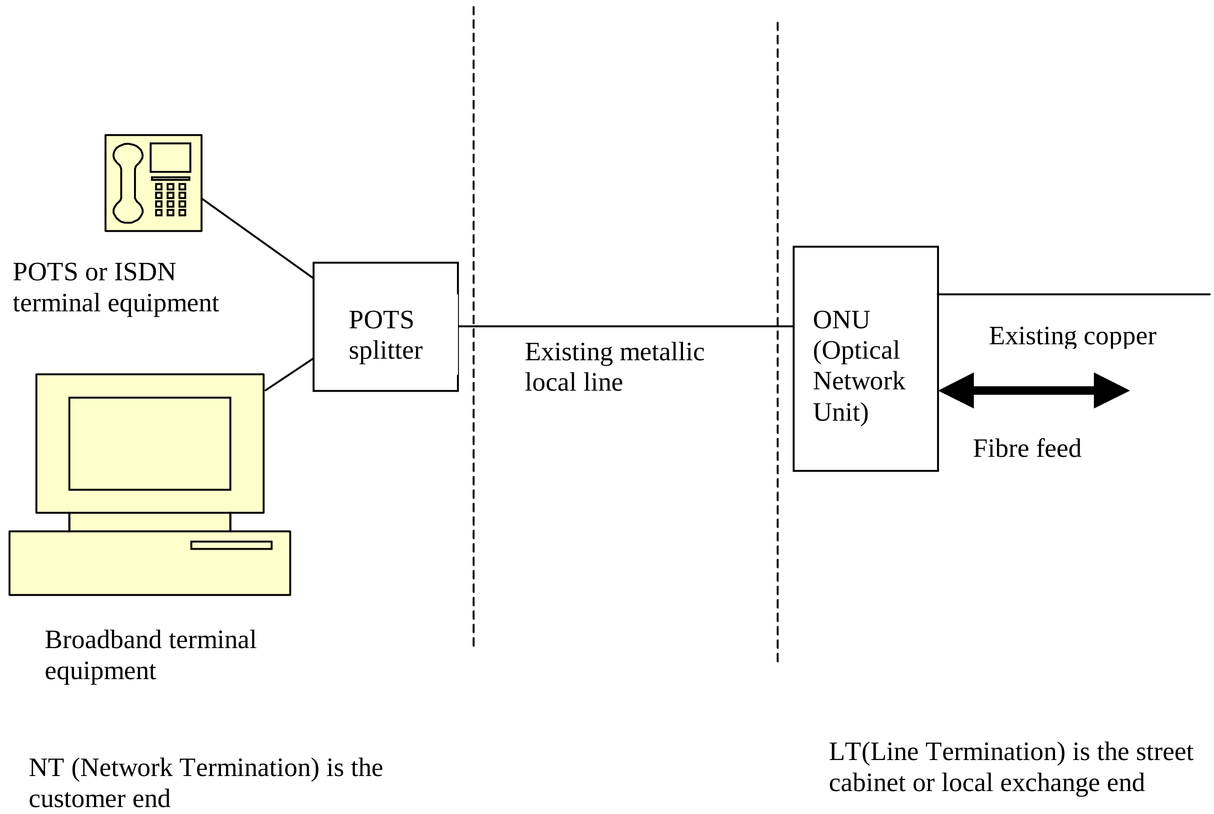


Figure 7.2: VDSL general reference model

The maximum length of line between the ONU and the NT does not appear to be defined in ETSI TS 101 270-1 V1.2.1. However test loops are defined in the standard up to a length of 2100m suggesting that this may be the maximum deployable length.

7.2.1 Choice of launch model

From the topology of Figure 7.2 it was concluded that the Drop1 launch model used for ADSL groundwave propagation described in section 6 was appropriate. Drop2 includes an additional length for household wiring which would not be the case when a POTS splitter exists. On inspection of the antenna efficiency tables the storey models are very similar to the Drop 1 efficiency at VDSL frequencies. Consequently only the Drop1 model was used in this analysis as a building block for cumulative emissions.

7.2.1.1 Drop1 antenna efficiency at VDSL frequencies

In the study for ADSL groundwave propagation it was found that the antenna efficiency of the NEC models was much greater than actual twisted pairs. To adjust the model to allow for "balance" it was found that subtracting 50dB from the NEC value gave good agreement with experiment at ADSL frequencies. For higher frequencies the situation is summarised in Table 7.7.

Freq. (MHz)	NEC vertical validation case antenna efficiency (dBi)	Difference from experimental unbalanced (dB)	Difference from experimental balanced (dB)	Drop1 NEC gain compensated for [8]unbalance experiment (dBi)	Drop1 NEC gain compensated for balance experiment (dBi)
4	-14.2	-40.8	-78.8	-47.6	-85.6
6	-11.4	-35.6	-74.6	-39.7	-78.7
10	-8.2	-12.8	-70.8	-15.6	-73.6
15	-6.4	-26.6	-48.6	-31	-53

Table 7.7: Drop1 compensation for balance based on experimental result

As can be seen the antenna efficiencies for both the balanced and unbalanced cases are generally much lower than the antenna efficiency used in the calculation for cumulative PLT coverage discussed in section 3. From this it was anticipated that cumulative ambient levels would be lower than those calculated for PLT interference. Consequently it was decided to investigate a worst case scenario for VDSL. The Drop1 antenna efficiency for the compensation of Table 7.7 is graphed in Figure 7.3.

[8] The experiment was termed unbalanced because the twisted pair side of the balun was shorted to the coaxial feed outer. However there will still be some balance effect as magnetic fields from the cable will still cancel irrespective of whether the cable is driven balanced or not.

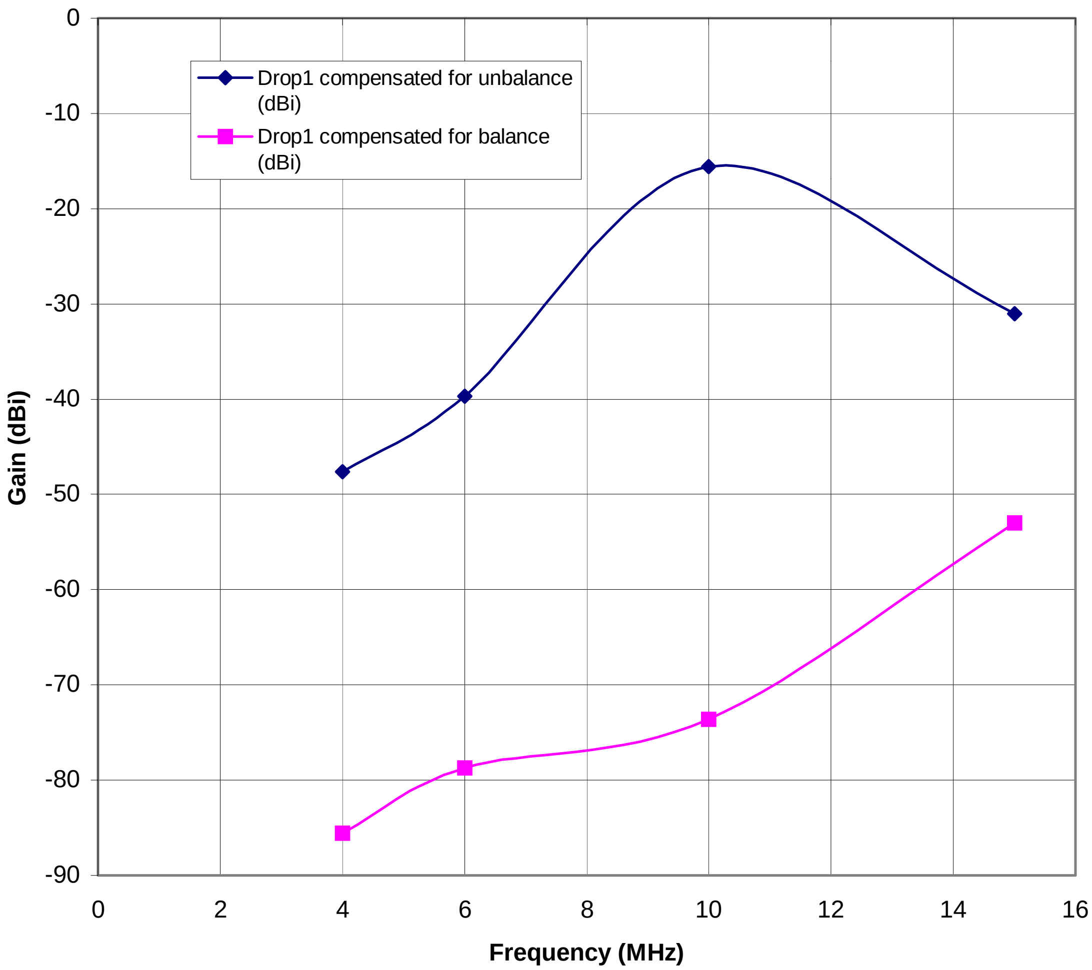


Figure 7.3: Antenna efficiency of Drop1 for balanced and unbalanced cases for compensation of Table 7.7

7.2.2 Effect of frequency on cumulative skywave propagation

The critical frequency is the highest frequency that will be returned down to earth for a wave beamed at the ionosphere with normal incidence[xviii]. The upper limit of critical frequency is approximately 12MHz however it can be as low as 5MHz for certain conditions. This has important implications for propagation of VDSL frequencies. Above 12MHz there will be no localised increase in ambient due to skywave, as all frequencies beamed directly up from a city will go through the ionosphere and not bounce back down. Inspection of the graphs in Appendix 2 revealed that conditions on a February evening would most strongly propagate the VDSL emissions. Figures 7.4 and 7.5 illustrate the situation more thoroughly for propagation from London on a February evening. Figure 7.4 shows the case at 8MHz where the field is strongest in the vicinity of the antenna. This indicates that the critical frequency has not yet been reached. Figure 7.5 shows the situation at 9MHz where the field is no longer strongest in the vicinity of the antenna. This indicates that the critical frequency has now been reached and therefore the critical frequency is approximately 9MHz. From this we can conclude that 8MHz is the worst case frequency for cumulative VDSL propagation as antenna efficiency increases with frequency, however, above this frequency localised increases in skywave propagated ambient will not occur as the radiation will pass through the ionosphere.

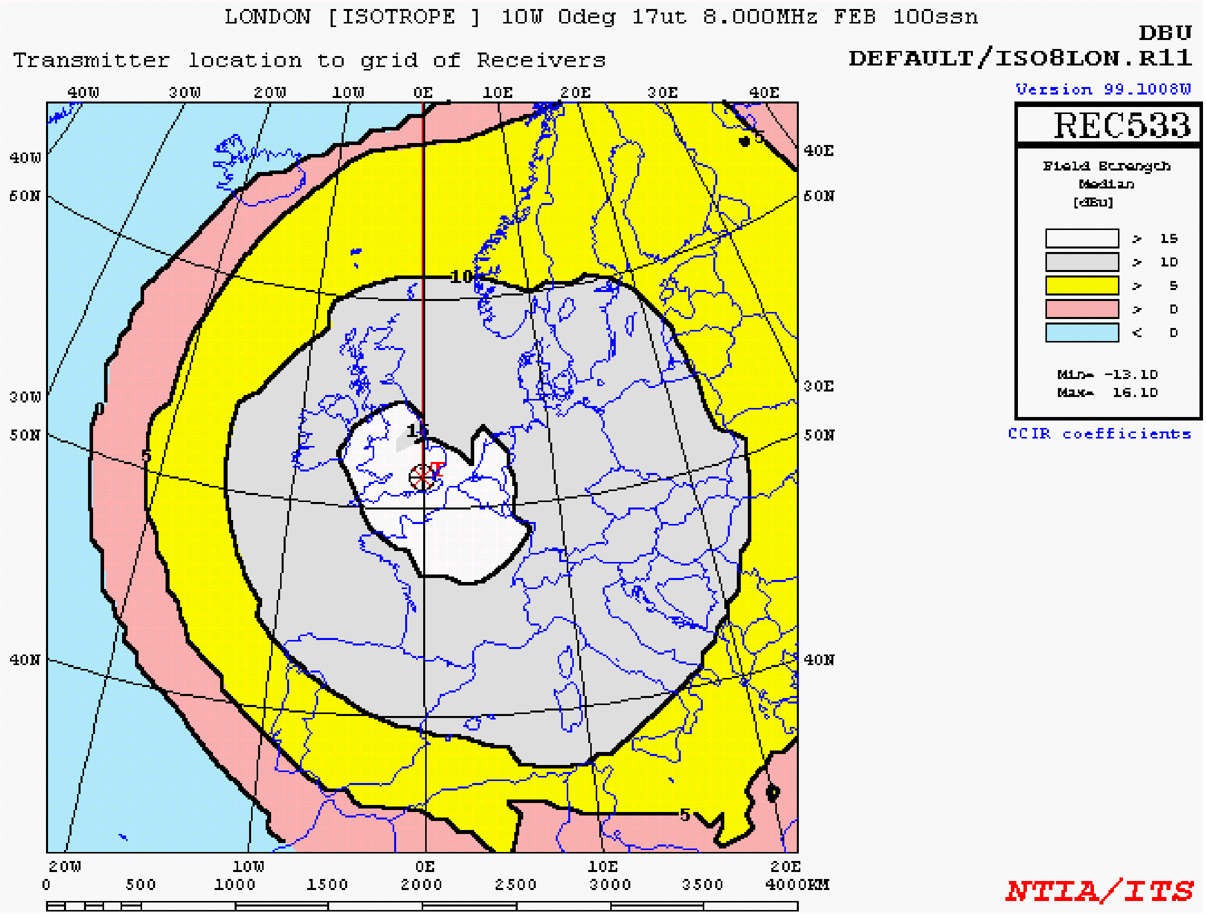


Figure 7.4: Isotropic area coverage at 8MHz from London just below the critical frequency

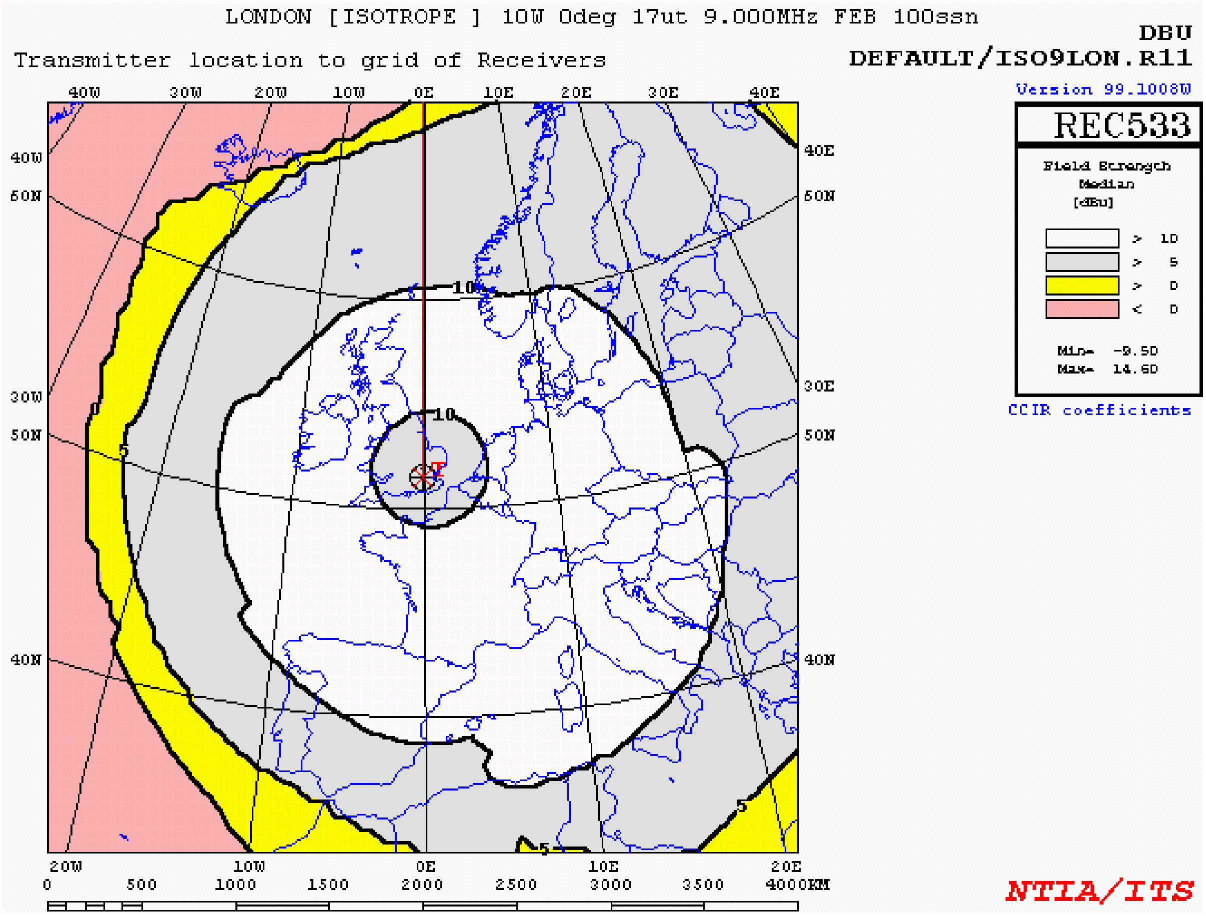


Figure 7.5: Isotropic area coverage at 9MHz from London just above the critical frequency

7.2.3 Summation of cumulative VDSL emissions from major UK cities and Ruhr area of Germany

From the knowledge of the likely antenna efficiency and propagation effects above 8MHz a worst case cumulative skywave emissions value was estimated. The approach taken was the same as for the PLT case described in section 3. The following assumptions were made:

Housing density

A density of 1000 homes per square km.

Market penetration

The technology is taken up in 25% of homes.

Antenna efficiency

From Figure 7.3 the antenna efficiency at 8MHz is –25dBi for the unbalanced case.

Launch power

From ETSI TS 101 270-1 V1.2.1 (1999-10) the launch power is –20dBm in a 10kHz bandwidth at 8MHz

Antenna pattern

Inspection of the Drop1 antenna pattern revealed an essentially isotropic shape as far as skywave propagation was concerned. Consequently an isotropic antenna was assumed for coverage purposes.

The coverage pattern of Figure 7.4 was assumed to apply for all the sources listed below. The source power used in Figure 7.4 was 10W therefore each of the sources was compensated by an amount dependent on its source power relative to 10W. The situation is shown in Table 7.8.

City/area	Area (km^2)	Total drops for 25% penetration	Total power radiated at 8MHz (dBm)	dB down on 10W (dB)	Field over UK (dBuV/m)	Field over UK (V/m)	Power (W/m^2)
Ruhr	3507.00	876750	14.4287	25.57	-10.57	2.96E-07	2.33E-16
London	2500.00	625000	12.9587	27.04	-12.04	2.50E-07	1.66E-16
Birmingham	900.00	225000	8.5217	31.48	-16.48	1.50E-07	5.97E-17
Manchester	625.00	156250	6.9381	33.06	-18.06	1.25E-07	4.14E-17
Glasgow	375.00	93750	4.7196	35.28	-20.28	9.68E-08	2.49E-17
Liverpool	300.00	75000	3.7505	36.25	-21.25	8.66E-08	1.99E-17
Leeds/Bradford	275.00	68750	3.3726	36.63	-21.63	8.29E-08	1.82E-17
Stoke on Trent	218.00	54500	2.3639	37.64	-22.64	7.38E-08	1.45E-17
Nottingham	187.00	46750	1.6977	38.30	-23.30	6.84E-08	1.24E-17
Sheffield	180.00	45000	1.5320	38.47	-23.47	6.71E-08	1.19E-17
Bristol	150.00	37500	0.7402	39.26	-24.26	6.12E-08	9.95E-18
Edinburgh	120.00	30000	-0.2289	40.23	-25.23	5.48E-08	7.96E-18
Belfast	100.00	25000	-1.0207	41.02	-26.02	5.00E-08	6.63E-18
Leicester	100.00	25000	-1.0207	41.02	-26.02	5.00E-08	6.63E-18
Coventry	75.00	18750	-2.2701	42.27	-27.27	4.33E-08	4.97E-18
Cardiff	75.00	18750	-2.2701	42.27	-27.27	4.33E-08	4.97E-18
						Total	**6.42E-16**

Table 7.8: Total worst case cumulative VDSL skywave power over UK

The total electric field over the UK is then given by

$$Field(V/m) = \sqrt{(W/m^2)*377}$$

The total field is therefore 0.492μV/m which is –6dBμV/m.

8 INVESTIGATION OF PROPAGATION OF CUMULATIVE HOMELAN EMISSIONS

HomeLAN technology[xix] aims to use existing transmission media in the house for digital data transmission so that no new wiring need be installed. With this in mind there are three possible media that a HomeLAN system can use, namely: the existing mains wiring of the house, the existing telephone wiring in the house, or wireless transmission. In the UK wireless HomeLAN kits and kits which use the telephone cabling as the media are readily available. Kits which use the mains cabling as the media are not so freely available.

Vendors of Wireless HomeLAN kits appear to have a wide variety of methodologies to choose from when designing their equipment. Three frequency bands are used: the 2.4GHz microwave oven ISM band; the 1.88 to 1.9GHz Digitally Enhanced Cordless Telecommunications (DECT) band; or the 5GHz Broadband Radio Access Network (ETSI BRAN). All these methodologies appear to be using bona fide radio transmission and as such unintentional pollution of the radio spectrum should not occur.

The other two possible media, telephone cabling and mains wiring, are likely causes of unintentional radio spectrum pollution. Cumulative propagation from the mains wiring is investigated in the following section. Further experimental work is required for the telephone HomeLAN work. Therefore work relating to this is contained in an Annex to this report which will be available in due course.[9]

8.1 HomeLAN with mains cabling as the transmission media

8.1.1 CEBus EIA600

The proliferation of mains sockets in the home makes this a superficially appealing technology. However high speed data transmission over the mains is technically difficult. As such there appears to be only one standard that deals with high speed data transmission over mains cabling. CEBus EIA600[xx] is an open standard that has many sub-standards allowing power lines, category 5 cable, coaxial cable, wireless and infra red as the transmission media. Specifically EIA-600.31 "Power Line Physical Layer and Medium Specification" deals with mains transmission. Its transmission frequencies are between 100kHz and 400kHz. The carrier sweeps its frequency from 100kHz to 400kHz in 25 cycles and is allowed 100μs to do this. The typical amplitude is 12Vpp into 300Ω. From this information the PSD was calculated to be –31dBm/Hz, which is 9dB higher than the PSD for PLT. However the

[9] See List of Annexes.

maximum transmission frequency is 400kHz at which λ=750m. It seems likely that the household wiring would be a much poorer antenna at these frequencies than at the PLT frequencies of 2.9 and 5.1MHz. However no precautions in the standard exist to prevent the HomeLAN signals propagating along the wiring feeding the house.

8.1.2 Skywave Propagation from Radiocommunications Agency HomeLAN unit

The Radiocommunications Agency have measured emissions from a "wireless telephone extension system". The system[xxi] comprises a base unit operating at 8.2MHz and an extension unit operating at 3.33MHz to provide full duplex communication over the mains wiring. To consider the cumulatively propagated skywave emissions from many such units a number of things need to be deduced. These are summarised below:

Power Spectral Density (PSD)

From the conducted emissions measurements provided in the Radiocommunications Agency report[xxi] the PSD of the two frequencies can be deduced. From these measurements it was found that at:

3.3325MHz the PSD is –40dBm / Hz

and at 8.2MHz the PSD is –50dBm / Hz

Antenna Factor of House for Extension unit (3.3325MHz)

This was derived from the Radiocommunications Agency loop antenna measurements. At 45m from the house the emissions were:

41.5dBμV / m = 118.8μV / m

Power flux density = V^2 / 377 = 3.744e-11W / m^2

$$EIRP = P\frac{4\pi 45^2}{2} = 4.764e-7\,W$$

Input power in 10kHz = 1mW

$$Gain = 10\log\frac{Pout}{Pin} = -33dBi$$

Antenna Factor of House for Base unit (8.2MHz)

Similarly at 45m from the house the emissions were:

36.5dBμV / m = 66.8μV / m

Power flux density = V^2 / 377 = 1.184e-11W / m^2

$$EIRP = P\frac{4\pi 45^2}{2} = 1.506e-7\,W$$

Input power in 10kHz = 0.1mW

$$Gain = 10\log\frac{Pout}{Pin} = -28.2dBi$$

<u>Technology Penetration</u>

It was assumed that 5% of homes had taken up the technology. For Greater London a density of 1000 homes/km² was assumed and therefore 50 homes/km² with mains media HomeLAN units. The propagation assuming an isotropic source antenna is shown in Figures 8.1 and 8.2. It should be noted that summing the house pattern at 8.2MHz produced an antenna pattern with a null at 90° elevation. This suggests the isotropic result in Figure 8.2 is very much a worse case. It should be further noted that at 18.00hrs 8.2MHz is above the critical frequency and the localised field is therefore much reduced.

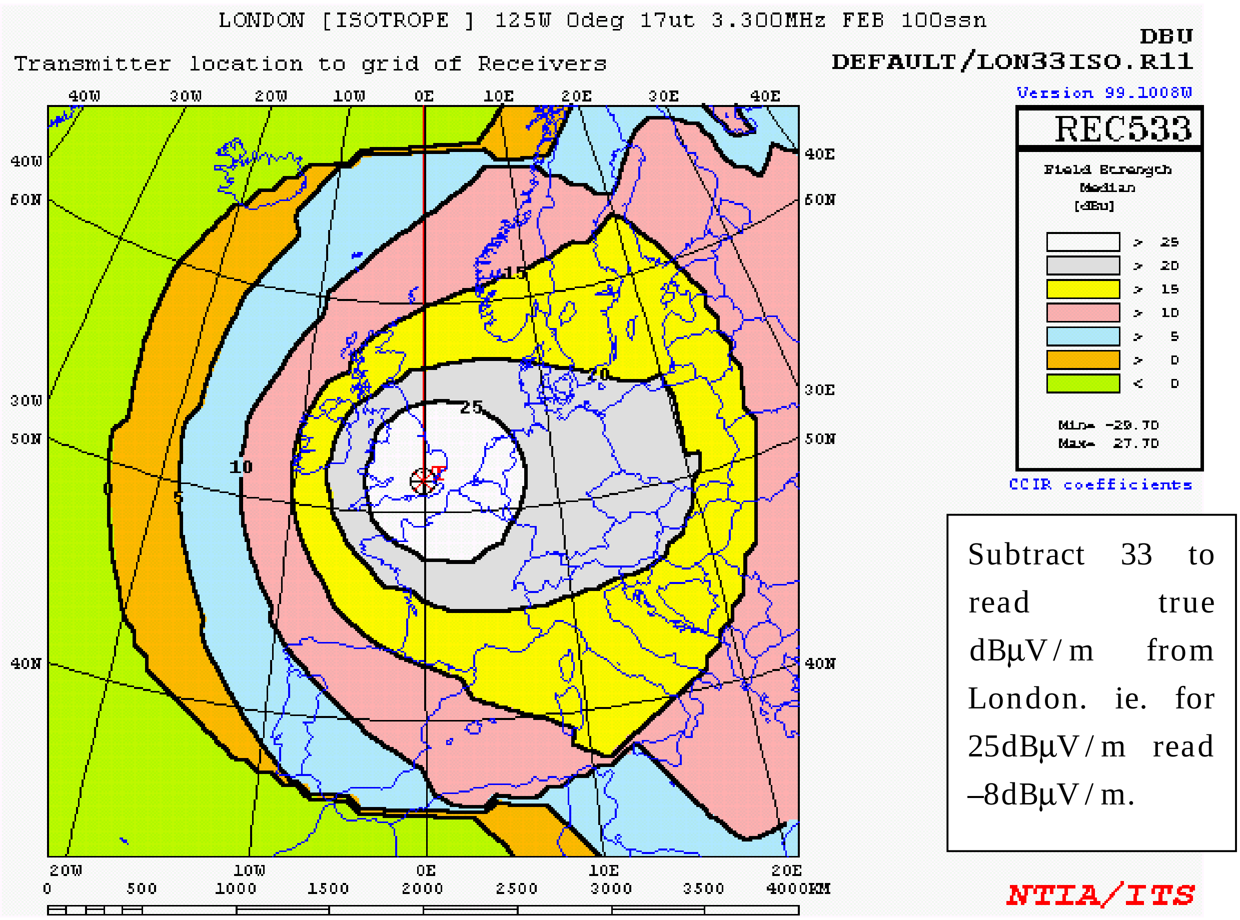
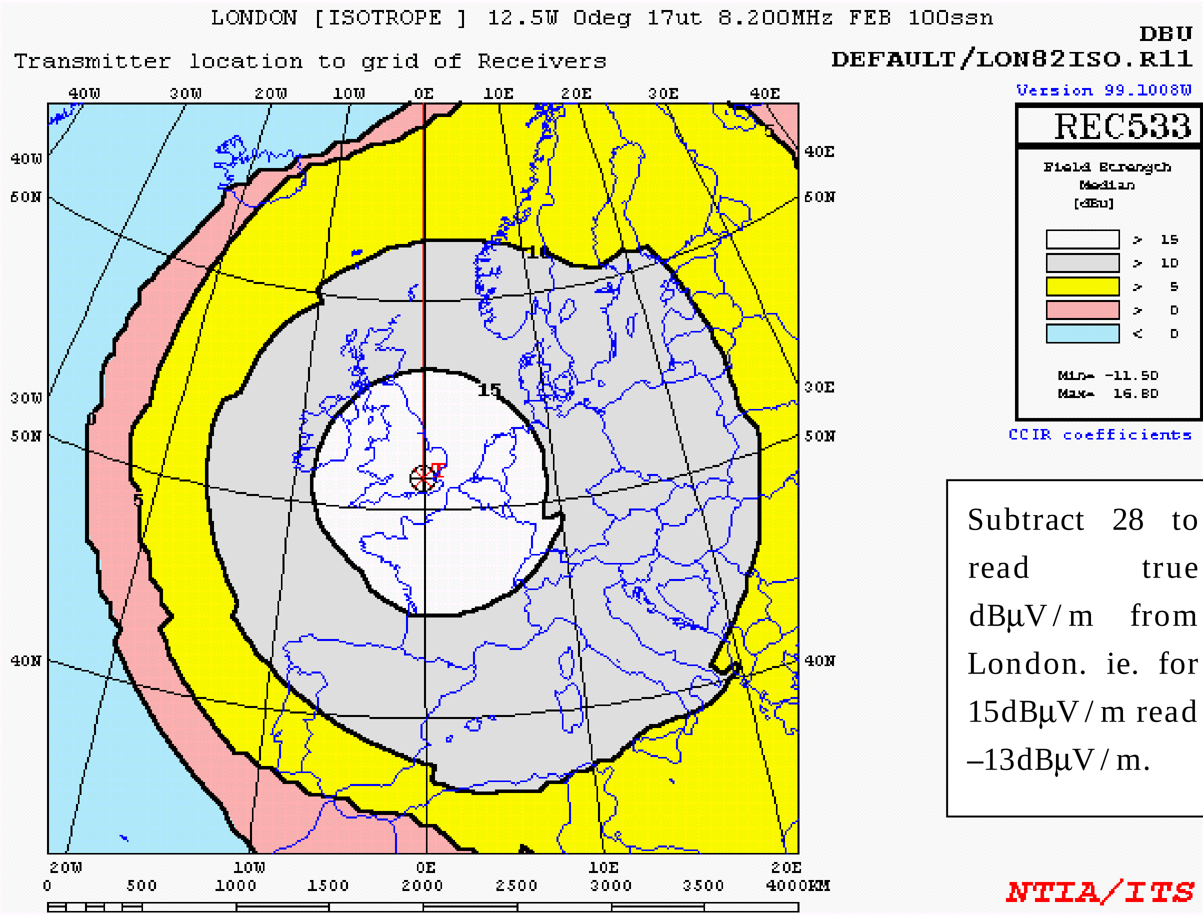


Figure 8.1: Cumulative propagation of Greater London with 5% penetration of mains HomeLAN

Inspection of Figure 8.1 reveals a maximum field of –6dBµV/m, which is 16dB below the daytime radio noise floor. This suggests that a significant increase in the radio noise floor due to cumulative skywave propagation is unlikely.



Subtract 28 to read true dBµV/m from London. ie. for 15dBµV/m read –13dBµV/m.

Figure 8.2: Cumulative propagation of Greater London with 5% penetration of mains HomeLAN

9 SPECTRUM MANAGEMENT ISSUES

The potential electromagnetic pollution problem manifests itself by the simultaneous transmission of radiation by the ground, space and sky wave propagation modes. It has been seen that the widespread deployment of ADSL and VDSL will result in the rise of the established radio noise floor in areas at short distances away from the effective radiation centres. This section advises on how the deployment of xDSL technologies might affect the flexibility of future spectrum planning decisions and any deployment of new radio services, including relevant financial implications.

9.1 Present spectrum allocation in the UK and xDSL

The current spectral allocation in the United Kingdom within the radiatively important xDSL frequency band (100 kHz - 10 MHz) was given in Table 1.3. From the spectrum management point of view, it is highly desirable that the services listed in Table 1.3 coexist harmoniously with new xDSL services. At present, though, and in the light of recent field trials as well theoretical studies, it is feared that the introduction of new radio regulations may be necessary to try and ensure minimal disruption to service providers. It is however, very difficult to predict what the overall effect of widespread deployment of xDSL technology will have upon existing and future services. This is mainly because both the potentially competing radio services and xDSL have not yet been fully deployed. In the following and based on the theoretical findings of section 6 an assessment will be presented on the overall impact of widespread deployment of xDSL on existing and future radio services. It must be noted, however, that the analysis presented here is largely based on theoretical findings, which are yet to be experimentally verified.

9.2 The effect of xDSL on AM radio broadcasting services

In the United Kingdom the two main frequency bands allocated to AM broadcasting are subject to potential interference from xDSL. This potential interference is very difficult to be quantified in a general and predictable manner, because it is a function of the relative location of the AM station, the xDSL emission field spatial distribution and the co-location of the AM receiver. This clearly dictates that no generalisations can be made, but each case should be considered on its own merit. A detailed analysis for such an individual case which is thought to probably represent a worse case scenario is given below. In the analysis presented only the xDSL ground-wave electric field contribution has been considered since it is orders of magnitude greater than the corresponding sky-wave field. It must be noted that this does not consider near field effects.

9.2.1 Established analogue MF broadcasting services

In the selection of a transmitter site for an analogue AM broadcasting station, the objectives are to provide adequate service to a metropolitan[10] area (in which the studio is normally located), and to adjacent areas with a minimum of interference to and from other users of the radio spectrum. While a minimum intensity of 25mV/m (88dBμV/m) is desirable to provide a broadcast service to the business and/or factory areas of a city, normally a minimum field intensity of 5mV/m (74dBμV/m) is required for a residential area. These values are necessary to offer good quality reception during night-time where asynchronous ionospheric interference from other transmitters raises the radio noise floor substantially. The maximum level of interfering signal from adjacent channel stations on the night-time protected ground-wave contour of a station is as follows:

Frequency separation between stations	**Maximum level of interfering ground-wave signal**
0 kHz	0.1 mV/m (40 dBμV/m)
10 kHz	0.5 mV/m (54 dBμV/m)
20 kHz	15.0 mV/m (83.5 dBμV/m)

Table 9.1: Typical permissible interference electric field strengths for adjacent channel stations

Let us now consider a typical analogue AM station serving an ITU designated metropolitan area. The AM station is located at an appropriate location (it is assumed that interference issues, human safety aspects, electrical safety and conformity to certain regulations are all dealt with satisfactorily) intending to serve several metropolitan areas enclosed by a circle of radius of about 50km. According to the customary transmitter design procedures, the fringes of the metropolitan area must be enclosed by the 5mV/m contour. Thus, let us say that at 50km the required electric field is E = 5mV/m or 74dBμV/m. This value of electric field strength is sufficient to provide a worse case signal to noise ratio of 30dB at the input of the receiver. (At the AM broadcasting band, the typical portable receiver comprises of a small loop antenna consisting of a coil in the tuned input circuit of the receiver). Such a SNR is necessary for good quality AM reception in the presence of an interfering electric field strength of 0.158mV/m. Assuming ground conductivity σ

[10] A metropolitan area is considered to be any area where there are located in reasonably continuous fashion, industrial or residential buildings on parcels of ground normally referred to as building lots.

=10mS/m, relative permittivity ε_r =15 and transmitter power P_t = 1kW the electric field predicted by the appropriate propagation chart is 64.57dBμV/m at d = 50km. A correction factor CF = 9.41dB is thus required to lift the field to the desired value of 74dBμV/m. This results in a minimum transmitter power P_t = 8.73kW, but allowances for degradation of components and changing ground parameters lead to a more realistic value of P_t = 10kW which is typical of many low power analogue AM transmitters found in the UK.

The analysis above, clearly suggests that AM electric field values are clearly above the ADSL and VDSL cumulative emission fields when they are considered at distances greater than 1 km away from the effective radiative centres. It must be noted here, that theoretical calculations do suggest a 10 to 30dB rise to the daytime established radio noise near selected areas. Nevertheless, for AM broadcasting coverage calculations, much higher noise levels are usually considered, usually about 20-30 dB above the established radio noise floor. It is therefore concluded that the far-field ground wave resulting from the widespread deployment of xDSL technologies is unlikely to affect the quality of service offered presently by AM broadcasters. This is true for the cumulative emission field at distances reasonably far from the effective radiation centre, i.e., of the order of at least 3km and for designated metropolitan areas. For rural locations at which much smaller field values are sufficient for good quality AM reception, xDSL near-field interference may affect radio reception in a very adverse manner. Since experimental measurements inside residential buildings are not yet available to the author, it is very difficult to assess the importance of the near fields, i.e., the field generated by the internal totally unbalanced wiring inside the customer's property. Nevertheless, this issue is quite important and should be addressed accordingly. The effect of xDSL near fields on the quality of AM reception can be evaluated in a straightforward manner, by monitoring the emissions and identifying the interference level at which quality of reception is adversely affected. Moreover, the effects of multiplexing, i.e., TDM and FDM as well as the modulation method, i.e., DMT with QAM linecode need to be assessed especially for digital MF radio transmissions.

9.2.2 Digital MF broadcasting

Broadcasters and network operators have an interest in introducing a digital system which could result in lowered operating costs whilst providing an ability to modify and continue to use many of their existing AM transmitters. However, the overriding success factor is likely to be in providing listeners with a service which is improved in both quality and consistency whilst providing the option of transmitting additional services. This can only be achieved by designing a system that enables the construction of receivers, which are both low in cost and simple to use. Furthermore, the receivers have to be made able to receive radio transmissions anywhere in the world. This led to the formation of the Digital Radio Mondiale (DRM) consortium, comprising of broadcasters, the radio industry, researchers and all those aiming at the development and introduction of a common global standard for digital transmissions in the AM bands. Obviously, with a digital system the receiver must be designed for the precise format of the signal, every last detail of the modulation, multiplexing and audio source coding, otherwise it will not function. At present the DRM standard is still under continuous development and no final decisions have been announced, it is thus very difficult to assess the impact of xDSL on such a system.

Nevertheless, preliminary information about highly likely features of the new digital standard was compiled by the author by accessing a series of web sites describing transmitter trials, proposed technical specifications, etc., as well as sharing valuable conversations with Mr Jonathan Stott of the BBC research and development department. After considerable elaboration to decide on what system parameters should be used in the analysis, the following requirements about the awaited DRM standard were reached:

- The new standard should accommodate for simultaneous analogue and digital transmissions at least for 10 to 15 years following the introduction of the digital system. The digital system is planned to be introduced in year 2001.
- Digital radio should be able, at some point to compete on an equal basis with current stereophonic FM transmissions, in order to secure a market, which will render the investment worthwhile.
- Digital transmissions should require less power than their analogue counterparts to service equal coverage areas.

The first requirement does not concern the digital format, but relates to the politics of gradual transition from the current analogue to the future all digital era.

Due to the narrow bandwidths (max 10kHz) of AM bands, a high state modulation and extremely efficient coding algorithms are required for transmission of data rates adequate to provide service comparable to current FM stereophonic quality. The compression algorithm has to be particularly efficient due to bandwidth limitations. Although a final decision has not been reached yet, it is highly likely that it will be based around MPEG-4 AAC. The appropriate incorporation of high coding gain and great flexibility in MPEG-4 AAC has opened up a wide field of applications. With sampling frequencies between 8 kHz and 96 kHz and any number of channels between 1 and 48, the method is well prepared to meet the needs of DRM. Compared to well-known source coding methods such as MPEG-2 Layer-2, it is possible to achieve half the bit rate with no loss of subjective quality.

The modulation scheme will be based on some variety of multi-carrier modulation, having something in common with the various forms of Coded Orthogonal Frequency Division Multiplex (COFDM) used in DAB and DVB-T. The principle of multilevel coding is the joint optimisation of coding and modulation to reach the best transmission performance. COFDM is particularly well suited to AM reception which is subject to multipath propagation, especially during the night when skywave interference is present. The candidates for the linecode scheme used to modulate the multiplexed data (MSC, FAC and SDC information[11]) at a low bit rate onto each carrier is QPSK, 16QAM and 64QAM depending on service requirements. The modulation schemes expected to be applied for FAC and SDC information are QPSK and/or 16QAM, whereas for the MSC a 64QAM or 16QAM may be applied, with the 16QAM aimed for high Doppler and delay spread modes. The FAC and SDC will be protected with a channel coding scheme which is much more robust than the coding scheme for the MSC. Error detection will be necessary for both. The maximum bandwidth efficiency for the MSC is $\log_2 64$ bits/s/Hz = 6, allowing bit rates of up to 48 kbps (including compression and error correction redundancy) capable of providing sound quality comparable to the current FM stereophonic standard. Initially, however, lower data rates of 20 kbps are anticipated to be used.

Let us now evaluate the performance of a digital MF radio transmitter in relation to the analogue MF transmitter example presented in section 9.2.1. The most important difference between the two worlds (digital versus analogue) in the context of AM broadcasting, is the excellent resilience of the digital system to sky wave interference. In the example of section 9.2.1, it was seen that the design criterion for an analogue AM transmitter was not the established radio noise floor, but the interference electric field value (adjacent-channel protection ratio). For the DRM digital transmitters many system parameters are yet to be finalised, including co-channel protection ratios between: two digital, digital and analogue, analogue and digital transmissions as well as adjacent channel protection ratios for all possible combinations of digital and analogue transmitters.

[11] The DRM multiplex consists of three channels: the Main Service Channel (MSC), the Fast Access Channel (FAC) and the Service Description Channel (SDC). The MSC contains the data for all the services contained in the DRM multiplex. The multiplex may contain between one and four services and each service may be either audio or data. The FAC is used to provide service selection information for fast scanning. The SDC gives information on how to decode the MSC, how to find alternate sources of the same data, and gives attributes to the services within the multiplex.

Nevertheless, preliminary RF protection ratio estimates for

- AM interfered with by digital signals,
- digital signals interfered with by AM,
- digital signals interfered with by digital signals,

for a system designed for 9 kHz spacing are shown in Tables 9.2, 9.3 and 9.4.

Δf / kHz	Protection ratio in dB	
	Shoulder distance 38 dB	Shoulder distance 43 dB
0	36	36
5	33	33
9	-2	-5
10	-4	-9
15	-7	-12
18	-10	-15
20	-12	-20

Table 9.2: Analogue signals interfered with by digital signals

The values shown in Table 9.2 are valid for AM signals with high compression and a modem receiver with an RF bandwidth of 4.4kHz and a slope of 40dB/octave. For normal compression the values are 6.5dB higher.

Δf / kHz	Protection ratio in dB
0	0
5	-4
9	Not available
10	-43
15	<-60
18	<-60
20	<-60

Table 9.3: Digital signals interfered with by analogue signals

The values shown in Table 9.3 are valid for an AM signal 25% modulated with coloured noise according to ITU-R BS.559 and for a BER of 1×10^{-4}.

Δf / kHz	Protection ratio in dB	
	Shoulder distance 38 dB	Shoulder distance 43 dB
0	15	15
5	11	12
9	-13	-13
10	-25	-29
15	-28	-33
18	-31	-35
20	-33	-37

Table 9.4: Digital signals interfered with by digital signals

The values shown in Table 9.4 are valid for a BER of $1x10^{-4}$.

In order to determine the necessary carrier-to-noise ratio for good quality digital MF reception, the standard of quality of the digital transmission needs to be specified in terms of the maximum acceptable BER. An appropriate value for stable audio signal without disturbances and which is superior in all audio quality characteristics to those of a class A analogue MW broadcast signal has been experimentally found to be $1x10^{-4}$. Table 9.5 gives simulated system performance anticipating perfect channel estimation and the absence of phase noise and quantization effects. Channel decoding is assumed to be done with a multistage decoder with 2 iterations. For channels 1 and 2 the ground-wave mode is applicable and for 3 and 4 the sky-wave. The associated error correction code rate is R=0.6 and the modulation is 64QAM. The signal power includes pilots and the guard interval.

Channel model	Channel Type	Mode of Propagation	C/N for BER=$1x10^{-4}$
Channel 1	AWGN	Ground Wave, LF, MF	14.9
Channel 2	Ricean with delay	Ground Wave, MF	16.0
Channel 3	US Consortium	Sky Wave, HF	22.7
Channel 4	CCIR poor	Sky Wave, HF	21.7

Table 9.5: Required C/N for a transmission to achieve a BER=$1x10^{-4}$ after the channel decoder for the MSC

As it can be seen, a pure Gaussian channel represents the best case scenario requiring a C/N of only 14.9dB. Nevertheless, for other types of channels and especially for those making use of the sky-wave mode of propagation a C/N ratio of 23dB is required. For a higher BER of $1x10^{-5}$ a C/N ratio of 24dB is required. Thus, by replacing the analogue transmitter of section 9.2.1 with a digital transmitter, possible power savings can be realised. Moreover, in digital transmissions all power is within the side bands, whereas in amplitude modulated transmissions with a modulation degree of approximately 30%, only 5% of the total power is in the side bands. Modern semiconductor AM transmitters can be used for digital transmissions and can provide efficiencies of up to 85% in LF and MF and up to 75% in HF. Therefore, further considerable savings can be made in terms of required RF power. A good example demonstrating the advantages of digital MF broadcasting against analogue AM broadcasting is that of Deutsche Telecom. Deutsche Telecom operates a low power (400W) solid-state transmitter PDM type with digital modulation in south-east Berlin. The transmission is on 810kHz. Figure 9.1 shows the location of the transmitter in Berlin, as well as its relative effective day and night coverages in comparison with a co-located 2.5kW AM transmitter whose daytime coverage is roughly equivalent to that of the digital transmitter.

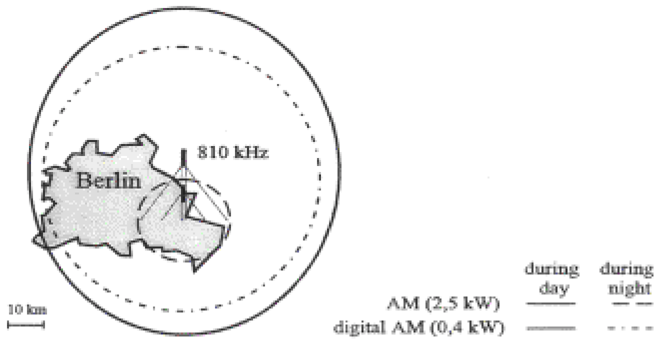


Figure 9.1: Comparison of the coverage areas of a digital and an analogue transmitter located in Berlin

In this example power savings of 8 dB were made possible with the added advantage of extended night-time coverage for the digital system.

From the analysis presented in this section, it is clear that if the adjacent-channel AM/DM protection ratio is used as the digital transmitter design criterion, the widespread deployment of the xDSL technology is not expected to cause any significant degradation to MF broadcasting within the denoted metropolitan service area. This holds true for the xDSL cumulative groundwave emission field at distances greater than 3km from the effective emission centre but not for the near emission fields generated in the vicinity of the customer's property, or at distances shorter than 3km. For rural areas where noise levels are particularly low, the effect of xDSL near fields are likely to be much more important, MF reception may be expected to be adversely affected. For MF receivers located less than 500m from an MDF, reception is likely to be severely impaired. Finally, the effects of xDSL multiplexing and modulation techniques on digital MF radio reception should be investigated and assessed. Existing evidence[12] in the context of digital television broadcasting has shown that an interfering source whose radiated emissions resemble broadband random noise has the greatest interference potential for DVB-T and DAB reception. It is noted that the preliminary DRM system specification suggests that the C/N difference for essentially error-free transmission and complete system failure is a few decibels.

Nevertheless, all MF analogue transmitters are going to be gradually replaced with digital ones and eventually will be phased out by year 2030. This is highly desirable not only for the service providers themselves, but for spectrum planning authorities too. Should all analogue MF transmissions cease to exist, much lower protection ratios (DM/DM) could be used as suggested by Table 9.4, which are typically 10 to 15 dB less than the currently assumed protection ratios (AM/DM) for analogue transmissions. The implication is a much quieter electromagnetic environment and therefore reduced radiation of digital transmitter power. This could be an especially welcomed development for the UK, where the current radio noise floor lies typically 10 to 15 dB lower than the values quoted in ITU-R P.372.

However, if xDSL emissions lie above the planned interference field value assumed in an all digital MF broadcast scenario, certain measures need to be taken to maintain quality of reception. The obvious way for digital MF broadcasters to compensate for such an increase, is by increasing their transmitter power. If for example a 5dB power increase is required, then the transmitter power will need to be tripled. Subsequently, all other co-existing digital radio stations will have to increase their transmitter powers to maintain a certain adjacent-channel protection ratio. The necessary engineering adjustments will need to be carried out in a collectively co-ordinated way requiring the efforts of several system engineers from different broadcasting entities and involving also preparation of new licence applications. The efforts required to restore the digital MF radio service may thus prove quite expensive. Moreover, the inconvenience of dissatisfied radio listeners and potential loss of revenue from advertising should be considered. On the other

[12] Lauder, D and Moritz, J, "Investigation into possible effects resulting from dithered clock oscillators on EMC measurements and interference to radio transmission systems", Report for RA REF: AY3377 (510001891), University of Hertfordshire, Regional Electronics Centre, December 1999.

hand, the financial implications of simply increasing a transmitter's power can not be easily quantified at the present time. It is expected that many broadcasters will retain their existing analogue front-end transmitter infrastructure. Today's AM transmitters are generally compatible with digital modulation inputs. One of the most obvious changes required is to modify the oscillator stage, but apart from that very few other changes are needed. Thus, the additional costs for the necessary power increase will be mainly carried by the possible replacement of a low-power solid- state transmitter.

Moreover, the issue of emission fields generated by the xDSL unbalanced wiring inside the customer's property needs to be taken into account. Since digital MF radio will eventually use much lower electric field strengths, there is a possibility for the useful field to be completely masked. Again, as in the case for analogue systems, the lack of experimental measurements inside residential buildings makes it impossible to assess the importance of the near fields. Nevertheless, this issue is of paramount importance and could lead to serious implications.

9.3 xDSL and aeronautical radio services

Other radio services likely to be affected by the widespread deployment of xDSL are aeronautical radiolocation and mobile services. In order to determine the effect of xDSL on present and future aeronautical services a complete and detailed specification of their operational characteristics is needed. It was not possible to obtain such information during this study. A more detailed investigation is required to source and compile the relevant documentation and it is suggested that this be the subject of a further study funded by the RA.

Nevertheless, the radiation diagrams of the basic radiative elements associated with xDSL network topologies in Figures 9.1-9.4 show significant space-wave propagation. This is not to be confused with the sky-wave component, which is refracted by the Ionosphere and eventually reflected back to the Earth. The radiation patterns are plotted in the elevation angle plane. It is striking that most of the radiation is directed towards elevation angles ranging between 30 and 60 degrees. As a result, a calculation strategy of cumulative emissions is required to assess likely electric field values. Unlike the groundwave, which propagates by diffraction over the Earth's surface, the space wave does not lose additional energy to the ground. The space-wave electric field strength falls off inversely proportionally to the distance and as a consequence, high field values should be expected.

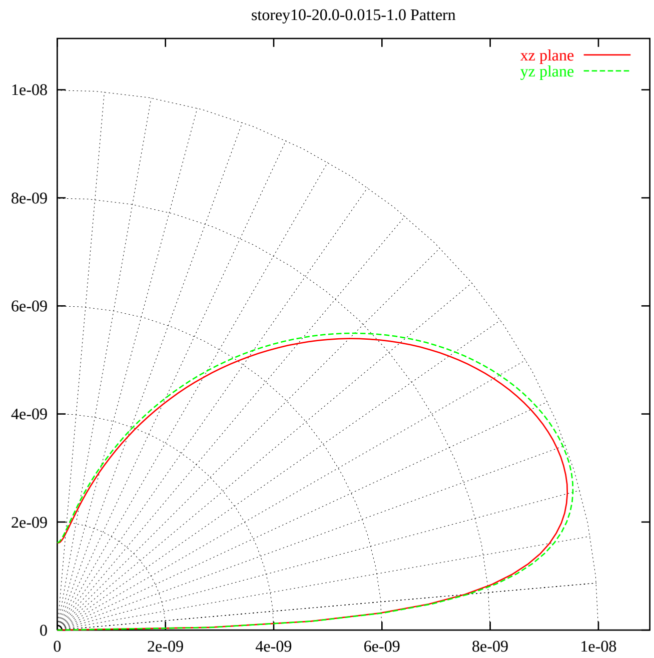


Figure 9.2: Radiation diagram of a remotely fed 10 storey long drop at 1 MHz.

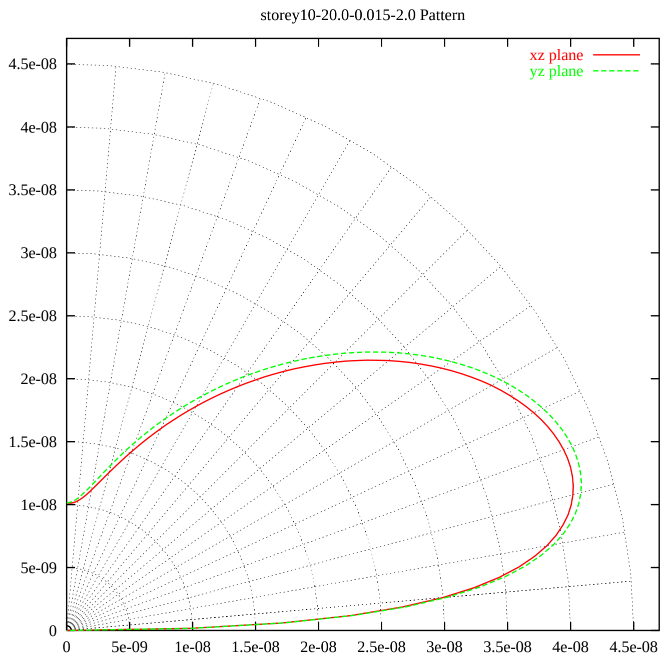


Figure 9.3: Radiation diagram of a remotely fed 10 storey long drop at 10 MHz.

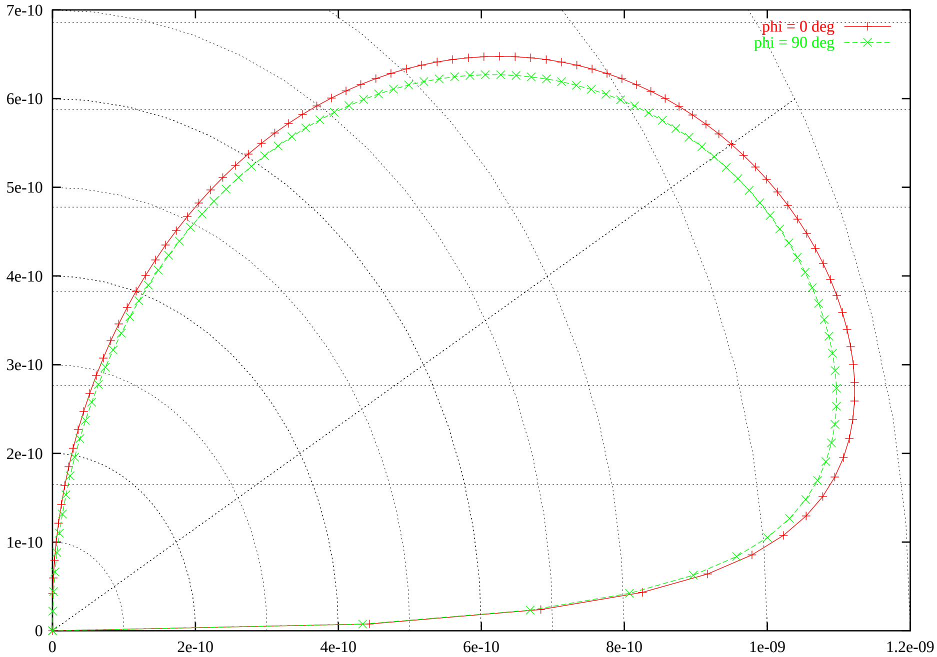


Figure 9.4: Radiation diagram of an MDF drop at 0.4 MHz.

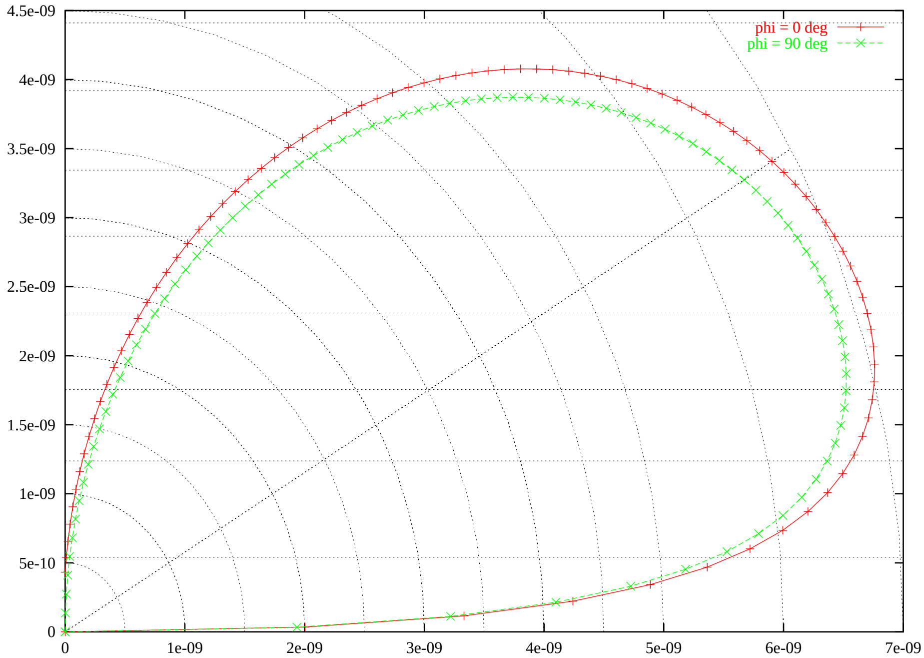


Figure 9.5: Radiation diagram of an MDF drop at 1.0 MHz.

9.4 xDSL and military communications

The effect of xDSL emissions on military communications has not been considered in detail in this report. Nevertheless, our cumulative emission field calculations clearly suggest that military communications will be adversely affected at selected areas. Before however definitive conclusions are drawn, a thorough theoretical study supported by exhaustive experimental evidence should be conducted. The military services likely to be affected concern mainly mobile communications.

9.5 Conclusions with respect to spectrum management issues

The effect of widespread deployment of xDSL on existing and future radio services from the spectrum management point-of-view has been considered. Especially for existing analogue and future digital services, both qualitative and quantitative approaches have been presented to advise on future spectrum planning decisions. For existing analogue MF broadcasting services the calculations suggest that they are unlikely to be affected by the cumulative xDSL groundwave at distances greater than 3km from the effective emission centre. Nevertheless, at shorter distances and inside customers' properties the xDSL near fields are thought to present a much more important threat to existing and future radio services. In any case, when analogue services are withdrawn and all MF broadcasting is converted to digital format, it would be useful to contain xDSL emissions at a maximum level of 20dB above the currently established radio noise floor. (For the UK lower values than those in the ITU-R P.372 could be used.) Such a regulation will guarantee minimal future disruption to digital MF broadcasting. At the same time, by setting the adjacent-channel protection ratio between digital transmissions at the same level (i.e., 20dB over the currently established radio noise floor), very low power solid state transmitters can be used to provide service to large areas. The resultant benefits will include a much quieter electromagnetic environment, substantial fossil fuel savings and reduction of greenhouse gases.

Finally, before any advice is given on how the deployment of xDSL systems could impact on the flexibility of future spectrum planning decisions, it is recommended that:

- A model for the calculation of cumulative space-wave emissions is developed.
- A detailed description of the operational characteristics of aeronautical NDBs and existing as well as future mobile communications is compiled.
- A further study is funded by the Radiocommunications Agency to enable a detailed assessment in this context.

- The effect of cumulative xDSL emissions on military mobile communications is rigorously assessed.

10 MITIGATION TECHNIQUES

This section discusses methods to limit the emission of far-field RF noise from both twisted pair and mains wiring.

10.1 Mitigation measures for ADSL & VDSL

10.1.1 Development of twisted pair standards

The main method for reducing crosstalk between pairs of wires is to twist them together. All POTS (Plain Old Telephone Systems) are wired with twisted pair. By the use of twisted pair and baluns, crosstalk between lines was kept down to acceptable levels. Although being party to distant conversations due to crosstalk was still a common occurrence up until the mid seventies. The use of Fibre optic cables for long haul transmission makes such crosstalk phenomena uncommon in the modern era. Crosstalk has long been an important consideration for telephone engineers. More recently twisted pair has become an important media for LAN applications. 10BaseT is the twisted pair version of Ethernet and the network is specified to transport 10Mbps. To obtain this data rate over twisted pair considerable improvements in the quality of the cable and interconnecting hardware had to be made over POTS wiring. The development was embodied in the EIA standards TSB36[viii] and TSB40[ix] which specified the category 5 cabling system. This cabling system has enjoyed great popularity throughout the '90s and represents a considerable improvement in quality as a transmission media compared to traditional POTS wiring. Further demands for improved data rate over twisted pair have brought forth an even higher standard of twisted pair quality, category 5e. The requirements for both cable and interconnecting hardware have been drawn together into one standard TIA/EIA 568-A-5[xxii] which forms the basis for the category 5e cabling system. At the time of writing this standard is still in draft form but elevates the twisted pair to a transmission media of previously undreamt of performance. The 5e standard allows simultaneous bi-directional transmission over 4 pairs. Test frequencies go up to 100MHz for category 5e, the same as category 5, but with reduced levels of crosstalk specified.

While the primary objective of the development of these standards is to reduce crosstalk between pairs the far field emissions should also be reduced.

The developments in the LAN industry do not appear to be mirrored in the telephone industry. The author is not aware of any standards development that exists in the telephone industry to enhance standards of existing cable infrastructure.

10.1.2 Crosstalk reduction

Crosstalk can be caused by electric or magnetic field coupling. For practical crosstalk situations both mechanisms will be present. Figure 10.1 shows how twisting the wire will cancel magnetic field crosstalk. If the number of twists is not even then the odd twist will still be susceptible to magnetic field coupling. In practice it is not possible to make sure that a termination is performed on an even twist number. However good quality cable (such as Category 5) will have a short pitch length so that the length of the odd twist is kept as small as possible.

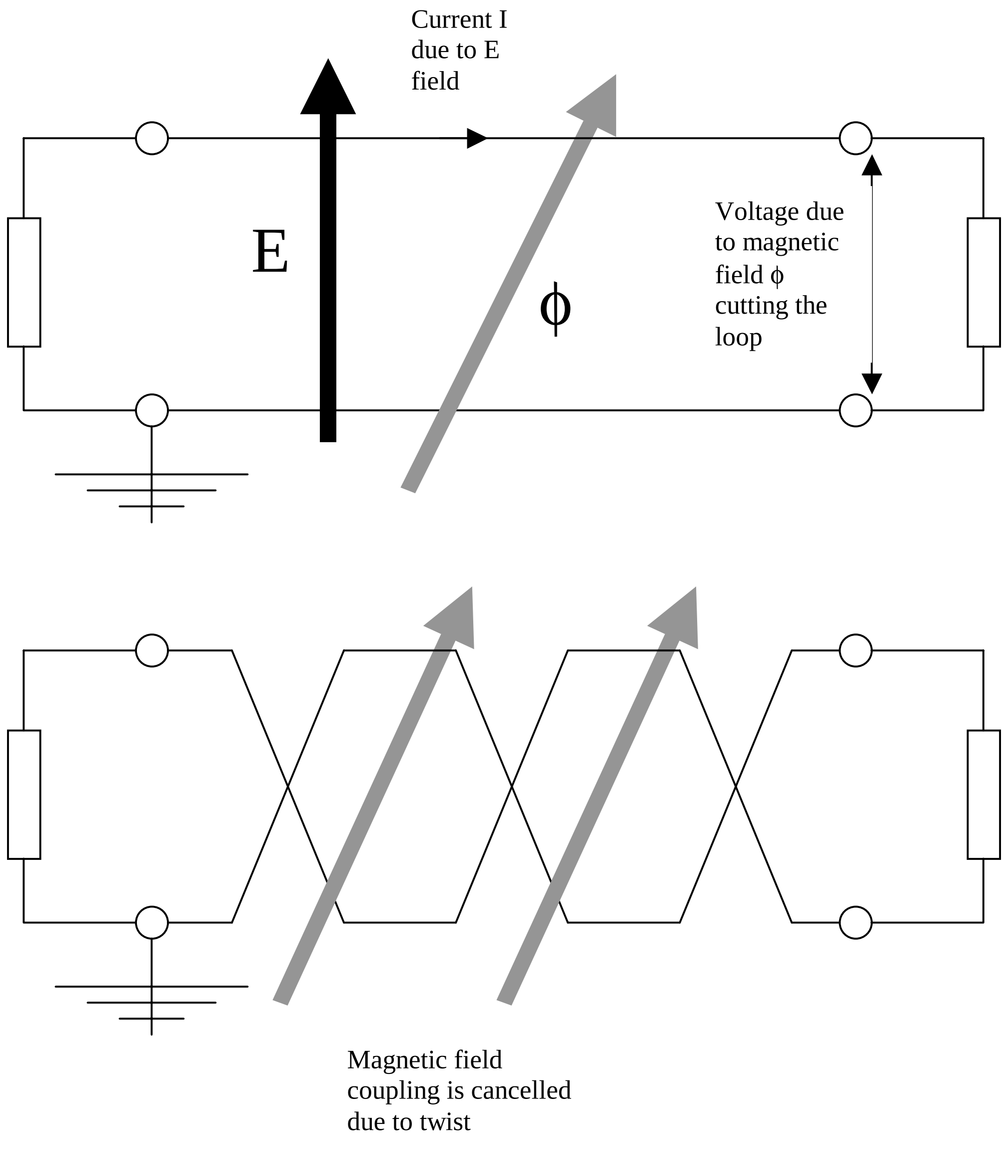


Figure 10.1: Cancellation of magnetic field coupling due to twist

Cancellation of electric field coupling is achieved if the pair is driven differentially or balanced. Balanced transmission is shown in Figure 10.2. Without a noise voltage

$$V = +V - (-V)$$

Adding a noise voltage to each wire of the pair illustrates how the electric field cancellation occurs.

$$V = (+V + Vn) - (-V + Vn) \quad \text{ie. Vn cancels}$$

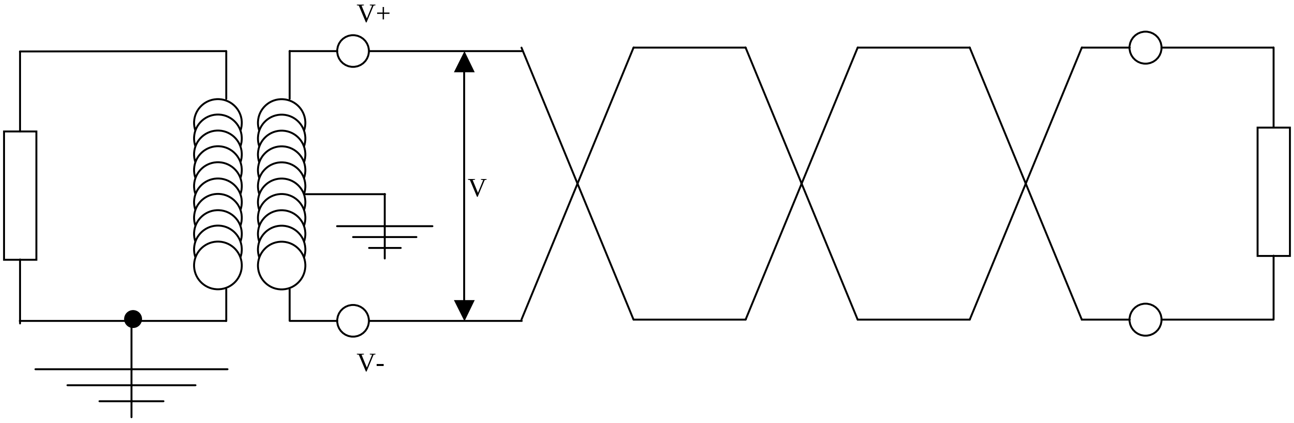


Figure 10.2: Twisted pair driven balanced

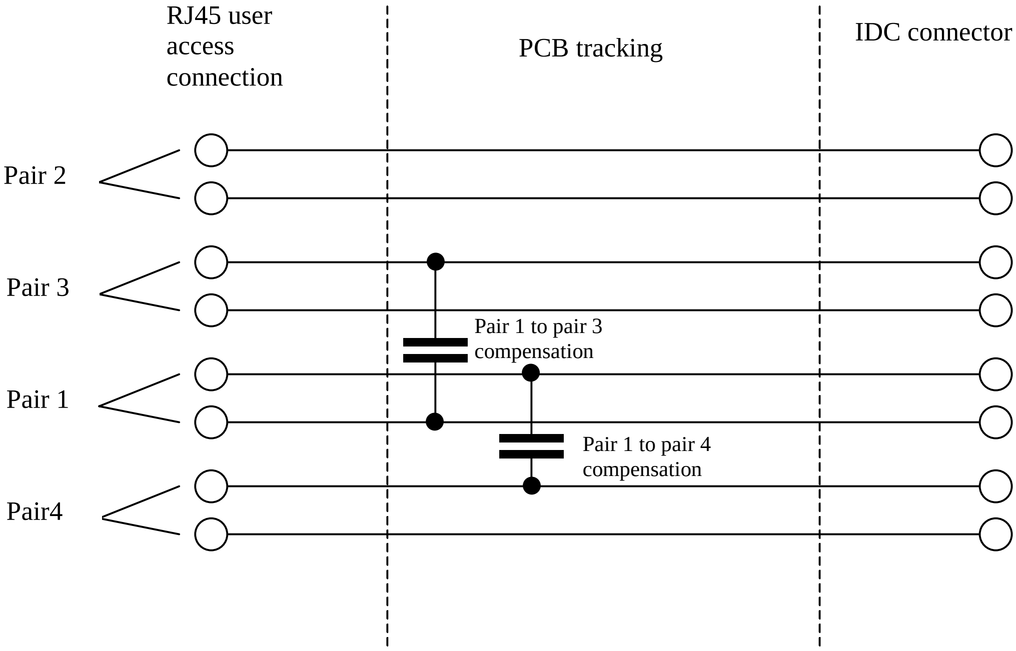


Figure 10.3: User access connection designed to eliminate crosstalk due to the odd twist

The effect of the odd twist is important and interconnecting hardware should be so designed that it effectively has an even number of twists. Patch leads designed for TSB 40 must use RJ45 plugs and sockets. To connect the twisted pair cable into an RJ45 plug requires that the wires must be laid parallel to each other and untwisted for approximately 13mm. The plug must be inserted into a socket, which also has parallel conductors. The plug socket combination adds up to a considerable untwisted length so opposite going twist must be built into the PCB to compensate. If this is not done then the balance of the system is destroyed by the interconnect.

The "opposite going twist" on the PCB can be provided by adding capacitance between the wires of the pairs. The values of capacitance are normally just a few pF, and can therefore be comfortably built in to the track design without the need for discrete components. A typical situation for a user access unit is sketched in Figure 10.3.

10.1.3 Reduction of far field emissions by improvements in cable and interconnection hardware

It has been assumed in the foregoing that measures designed to reduce crosstalk will also reduce far-field emissions from twisted pair cables. While this seems a reasonable assumption the author is not aware of any experimental evidence to show that the same rules still hold true. The effect of the odd twist with respect to crosstalk is well researched by Paul[xxiii] and is embodied in TSB 40 which specifies crosstalk levels for interconnecting hardware that can only be achieved with "an even twist". Assuming that far field emissions are reduced by the same orders of magnitude as crosstalk then reductions of far field emissions by as much as 30 to 40dB at 10MHz might be expected.

10.1.3.1 Costs of upgrading cable and interconnection hardware

Production costs of compensated interconnection hardware are no higher than uncompensated so in terms of gradual replacement of uncompensated plant for compensated there would be no appreciable cost. Better quality cable would incur some extra cost but in percentage terms of the cost of an installation this is unlikely to exceed a few percentage points.

10.1.4 POTS Splitter

Full rate ADSL requires a POTS splitter at both ends of the line. The situation is sketched in Figure 10.4.

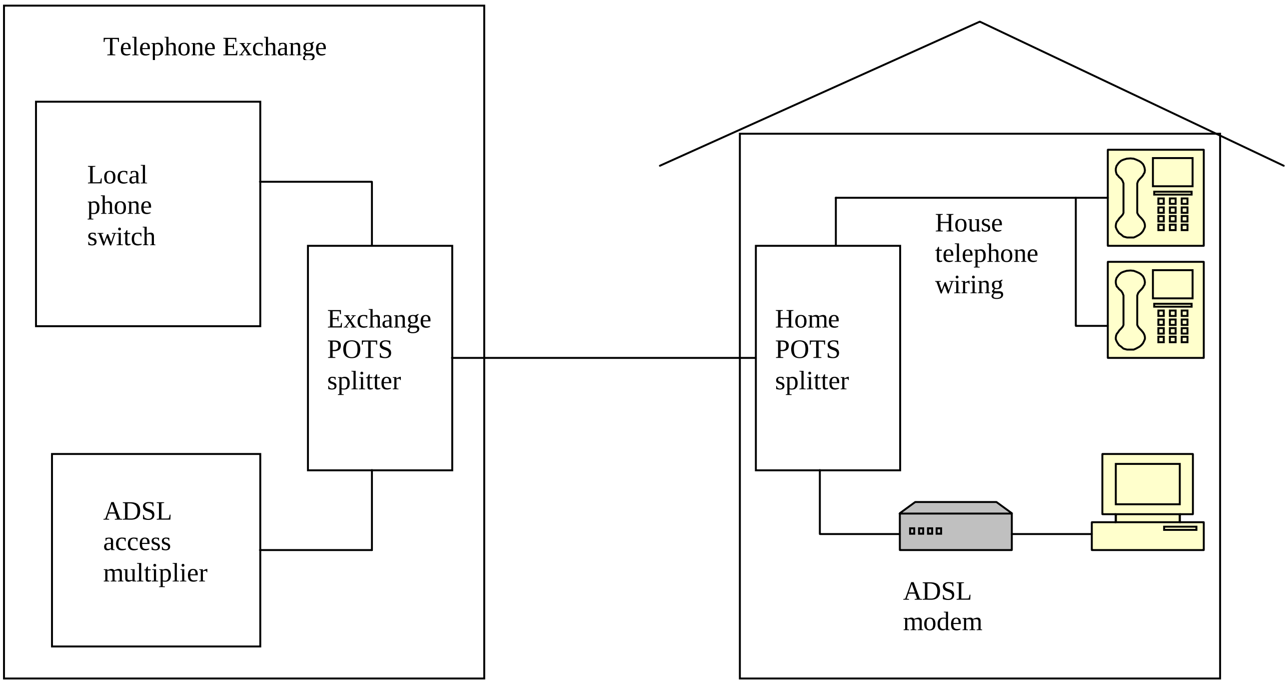


Figure 10.4: Full rate ADSL arrangement with POTS splitters

The POTS splitter allows only low frequency signals onto the house telephone wiring and only high frequency signals onto the ADSL modem line. This arrangement gives advantages in terms of immunity to noise for the ADSL operators. Also it reduces the potential emissions from the home phone wiring. Unfortunately a full rate ADSL service will require the telephone company to install the splitter at the user end. To avoid the need for a POTS splitter and hence a visit from a telephone engineer a splitterless version of ADSL has been proposed. The splitterless version only uses up to tone 128 (552kHz), above this frequency noise ingress becomes too much of a problem without the splitter. Even with the reduced frequency the splitterless version is still highly susceptible to noise. Clicks from a noisy handset are known to wreak havoc with the modem. It is understood that only the full rate ADSL has been trialled in the UK. From the point of view of reducing ambient noise pollution, the full rate service with splitter must be the preferred option.

VDSL is slightly different in that there is no splitter at the exchange end. At the other end of the copper line from the user must be an Optical Network Unit (ONU), as shown in Figure 10.5. Splitterless versions of VDSL have been proposed. As the frequencies in use are higher the house telephone wiring is likely to emit more than the ADSL case. Therefore once again the splitter must be the preferred method of installation.

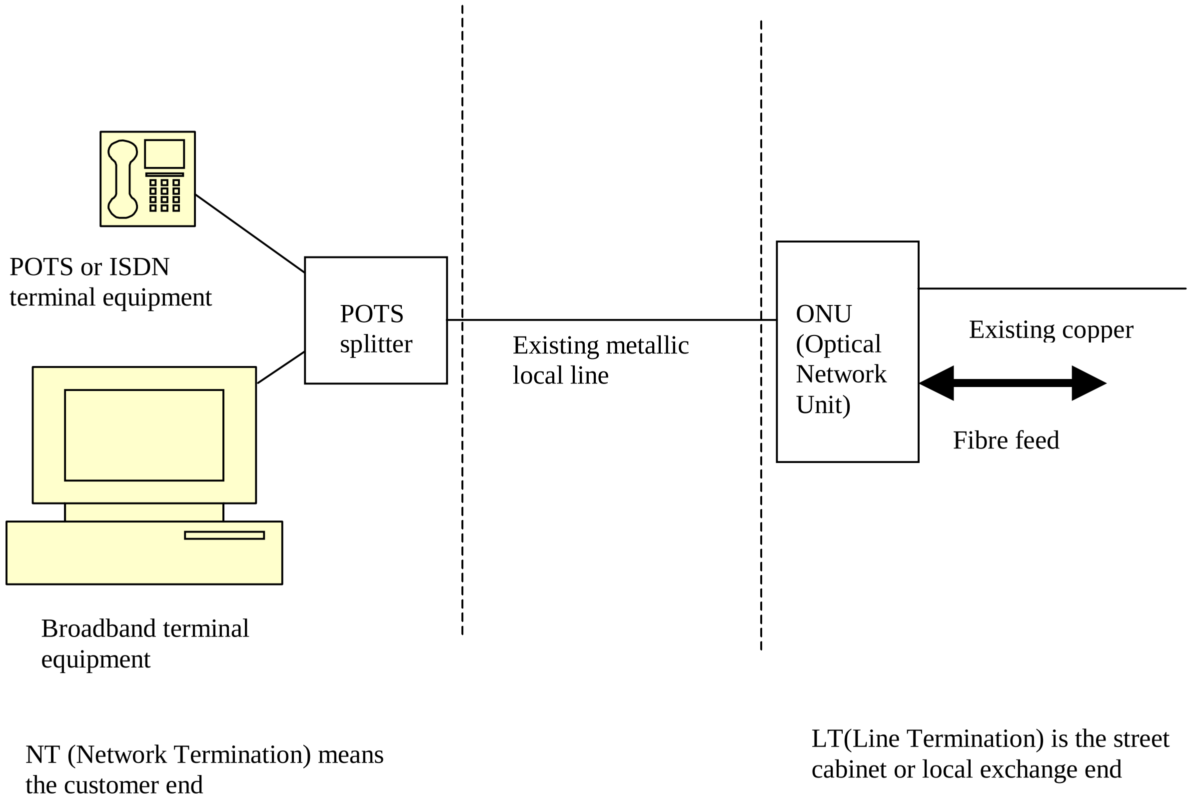


Figure 10.5: VDSL general reference model

Reducing the loop length from the ONU to the customer end will be helpful in reducing the cumulative radiated emissions effect on the ambient levels.

10.2 Mitigation measures for PLT

10.2.1 Mains conditioning unit

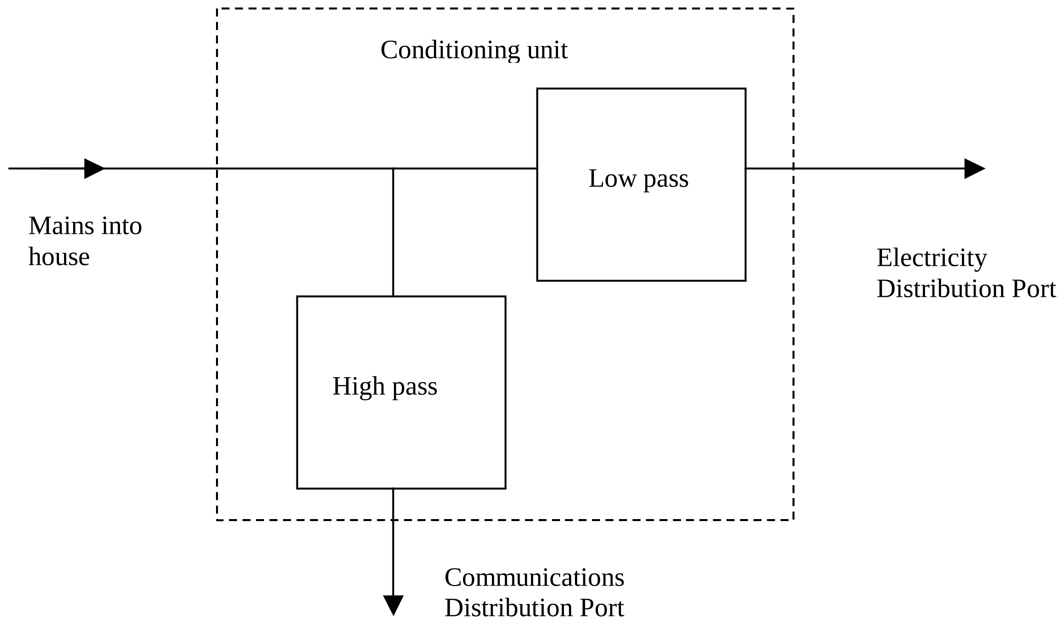


Figure 10.6: Mains conditioning unit

Brown[xxiv] proposes the use of a conditioning network to facilitate the transmission of signals above 1MHz on the low voltage distribution network. The conditioning unit is basically the same idea as a POTS splitter as discussed in the previous section. A block diagram is shown in Figure 10.6. Brown estimates that the attenuation of communications signals onto the mains wiring of the house to be between 30 and 50dB with the conditioning unit fitted. This kind of unit improves the performance of a PLT network at 3.3 and 5.1MHz from an operational point of view. Additionally, in order to reduce the contribution of signals to ambient levels, use of these units is highly desirable.

From the above it might be expected that further reductions in emitted levels could be obtained if RF filters were fitted at the base of lamposts and other street furniture. Extensive measurements were made on a row of lamposts connected together by an underground cable and were reported by Womersley et al[i]. From studying the reported measurements it could be seen that earthing the metal lampposts almost always reduced the emissions by typically 3 to 30dB. However the ambient level, measured with the feeder cable excited but no lamposts connected, acted as a floor to this reduction. It must therefore be concluded that the overall network emissions would not be improved upon if filtering were added to metal lampost bases. This of course assumes that metal lamposts would be earthed.

10.2.2 Exclusion zones

As far as ground wave propagation is concerned Stott[iii] gives exclusion distances for 3MHz frequency from a PLT installation. These values have been tabulated in Table 3.1.

10.2.3 Spread spectrum techniques

Use of spread spectrum techniques with some processing gain may allow reduction in the power spectral density required by PLT systems and therefore reduce emissions.

10.3 Conclusions with respect to mitigation measures

10.3.1 ADSL and VDSL

- Cables with good balance over the entire frequency range used by xDSL (25 kHz to 30 MHz) should be used to minimise emissions. In addition the balance and matching at interconnection points also needs to be of high quality. This is particularly important for VDSL and the other high frequency xDSL technologies which operate at much higher frequencies than the existing local loop infrastructure was designed to support. Results suggest that the cumulative emissions from an installation with an overall balance of 50 dB will not have significant impact on radio services. Improving the balance of the system will also reduce the level of noise ingress into the xDSL signal paths and thus increase the achievable data rate.
- The use of splitterless technology is not recommended.
- In the case of VDSL siting the ONU as close as possible to the end user is recommended.
- Exclusion zones, as discussed for PLT, would need to be employed for “sensitive receiving sites”

10.3.2 PLT

- The use of mains conditioning units is recommended to minimise the signal level present on the mains cabling of the house.
- Exclusion zones for PLT would need to be employed for sensitive receiving sites. The effectiveness of these would be limited by skywave propagation.

11 CONCLUSIONS

This study has considered the potential emissions resulting from the widespread introduction of broadband data access technologies, or wide band digital data distribution systems, operating over the electricity mains or the public telephone networks. The cumulative effects of these emissions on the established radio noise floor has been investigated and the resulting radio spectrum management issues addressed. Technologies considered have been:

- Power Line Transmission (PLT)
- Digital Subscriber Line (ADSL and VDSL)
- HomeLAN

The investigations have involved prediction of cumulative groundwave and skywave propagation of emissions as appropriate. Practical measurements have also been carried out on UTP systems in order to validate the ADSL and VDSL launch models.

The resulting predictions of far field emissions have been compared to the existing radio noise floor and the impact on the radio spectrum discussed.

A spreadsheet model to predict the groundwave propagation from ADSL/VDSL systems has been developed, allowing for a number of variables to be altered for an individual city or area, this includes the penetration of the technologies, the number of houses, bungalows, multi-storey buildings etc. Possible mitigation techniques to reduce these unintentional emissions have also been reviewed.

A number of conclusions can be drawn from this work and are presented in the following sub-sections.

11.1 Conclusions with respect to cumulative skywave propagation

From the results of the study groundwave propagation is the most significant mechanism for increasing the radio noise floor. Table 1.2 shows that significant increases in radio noise floor due to cumulative skywave propagation are unlikely. The worst case technology is PLT where an increase in radio noise floor due to skywave propagation up to 2 or 3dB is possible. All the other technologies studied appear unlikely to have any significant effect when only skywave propagation is considered.

Some interesting facts have been learnt about the cumulative skywave contribution to the radio noise floor.

1) Worst case conditions are on a February evening.

2) 8MHz is the highest frequency where localised increases in radio noise floor due to skywave propagation are likely to occur. Above this frequency the angle of incidence on the ionosphere must be significantly less than 90° for reflection to occur. Consequently localised field above 8MHz is propagated into space and not reflected back to earth.

3) The height of the F2 layer is such that any cumulative antenna pattern for a large city will be preserved.

4) The “localised area” coverage due to skywave propagation is typically tens of thousands of square miles. This is in distinct contrast to the effects from groundwave propagation which decay within a few tens of kilometres from the source.

5) An isotropic antenna is generally the worst case for localised increases in the radio noise floor due to cumulative skywave propagation. Nulls in antenna patterns at high elevation angles reduce localised increases.

11.2 Conclusions with respect to cumulative ADSL groundwave propagation

A novel and rigorous methodology for the estimation of cumulative emissions from the ADSL technology using metallic access cables for the provision of information services has been presented. The radiative characteristics of ADSL distribution configurations associated with typical residential and commercial buildings found in the UK were evaluated using NEC.

Using this methodology and assuming an arbitrary city profile, the applicability of the approach has been demonstrated. Cumulative emission electric field strength levels as a function of frequency, balance of cables and percentage of market penetration have been reported for several test cases. It should be very strongly stressed though, that the results and their interpretation in the context of this study apply only to the author's arbitrarily selected input model parameters, i.e., the particular city building makeup and average cable balance values. For realistic and accurate results, exact input data is required. Also the radiative characteristics of the network elements, in particular the MDF, are derived from simple numerical models which require validation. Once these issues are resolved, it will then be possible to draw more definitive conclusions. Nevertheless, the analysis clearly suggests that the cable balance is of paramount importance in the widespread deployment of the ADSL technology. If the technology is going to be deployed nationally, then good balance of cables will make any change in the established radio noise floor unlikely and no disturbance to existing radio services will be caused.

11.3 Conclusions with respect to cumulative VDSL groundwave propagation

A slightly modified version of the methodology used to calculate cumulative emissions from the ADSL technology has been utilised to assess the radiative emissions of the VDSL service. The radiative characteristics of VDSL distribution configurations associated with typical residential and commercial buildings found in the UK were evaluated using NEC.

Using this methodology and assuming an arbitrary city profile, the utility of the approach has been demonstrated. Cumulative emission electric field strength levels as a function of frequency, balance of cables and a typical saturation market penetration percentage of 20% have been reported for two typical test cases. It should be very strongly stressed though, that the results and their interpretation in the context of this study apply only to the author's arbitrarily selected input model parameters, i.e., the particular city building makeup and average balance of cables values. For realistic and accurate results, exact input data is required. It will then be possible to draw more definitive conclusions. The analysis clearly suggests that the cable balance is of paramount importance in the widespread deployment of the VDSL technology. If the technology is going to be deployed nationally, then a good cable balance value will ensure minimal disturbance to existing radio services.

11.4 Conclusions with respect to spectrum management issues

The effect of widespread deployment of xDSL on existing and future radio services from the spectrum management point-of-view has been considered. Especially for existing analogue and future digital services, both qualitative and quantitative approaches have been presented to advise on future spectrum planning decisions. For existing analogue MF broadcasting services the calculations suggest they are unlikely to be affected by the cumulative xDSL groundwave propagation at distances greater than 3km from the effective emission centre. Nevertheless, at shorter distances and inside customers’ properties the xDSL near fields are thought to present a much more important radiative threat to existing and future radio services. In any event, should analogue services be withdrawn and all MF broadcasting be converted to digital format, it would be useful to contain xDSL emissions at a maximum level of 20dB above the currently established radio noise floor. (For the UK lower values than those in the ITU-R 372 recommendation could be used.) Such a regulation will guarantee minimal future disruption to digital MF broadcasting. At the same time, by setting the adjacent-channel protection ratio between digital transmissions at the same level (i.e., 20dB over the currently established radio noise floor), very low power solid state transmitters can be used to provide service to large areas. The resultant benefits will include a much quieter electromagnetic environment, substantial fossil fuel savings and reduction of greenhouse gases.

Finally, before any advice on how the deployment of xDSL systems could impact on the flexibility of future spectrum planning decisions with regard to existing and future aeronautical services is given, it is recommended that:

- A model for the calculation of cumulative space-wave emissions is developed.
- A detailed description of the operational characteristics of aeronautical NDBs and existing as well as future mobile communications is compiled.
- A further study is funded by the Radiocommunications Agency to enable a detailed assessment in this context.

11.5 Conclusions with respect to mitigation measures

The following are measures which would reduce the possibility of excessive increases in radio ambient due to deployment of ADSL and VDSL technology.

- Cables with good balance over the entire frequency range used by xDSL (25kHz to 30MHz) should be used to minimise emissions. In addition the balance and matching at interconnection points also needs to be of high quality. This is particularly important for VDSL and the other high frequency xDSL technologies which operate at much higher frequencies than the existing local loop infrastructure was designed to support. The results suggest that the cumulative emissions from an installation with an overall balance of 50dB will not have significant impact on radio services. Improving the balance of the system will also reduce the level of noise ingress into the xDSL signal paths and thus increase the achievable data rate.
- The use of splitterless technology is not recommended.
- In the case of VDSL siting the ONU as close as possible to the end user is recommended.
- Exclusion zones, as discussed for PLT, would need to be employed for "sensitive receiving sites"

The following are measures which would reduce the possibility of excessive increases in radio noise floor due to deployment of PLT technology.

- The use of mains conditioning units is recommended to minimise the signal level present on the mains cabling of the house.
- Exclusion zones for PLT would need to be employed for sensitive receiving sites. The effectiveness of these would be limited by skywave propagation.

12 FURTHER WORK

12.1 Cumulative Ground and Sky Wave Emission

- The models rely on the quality of the input in order to derive accurate predictions of cumulative emissions. In particular the dispositions and proportions of the different types of property used in the example calculations are only indicative and not based on hard data. Real data should be sought to ensure that reasonable city compositions are used in the models.
- The radiation efficiencies of the different elements in the metallic access network are important parameters in the cumulative emission modelling. The launch models used in this study, derived from NEC2, are idealised and do not account for many aspects of the real physical system. For example shielding by walls and other structures will certainly have an impact. It is recommended that further extensive measurements on real telecommunication systems are carried out to both validate the launch models and provide direct input into the cumulative emissions model.
- The balance of the cables used in the metallic distribution networks has been shown to be of critical importance to the overall predictions of the models. Little information is available on the statistics of cable balance in the existing infrastructure at the frequencies used by xDSL technologies. It is also unclear how the balance in the system is likely to deteriorate with time. Extensive measurements of cable balance in the existing networks should therefore be made to determine the range and distribution of cable balance over the frequency range 100 kHz to 30 MHz.
- Long runs of overhead unshielded twisted pair cables are used in certain rural areas of the country (and in other countries) to provide access. The radiative characteristics of such long runs of cable has not been addressed by this report and should be assessed.
- Symmetric Digital Subscriber Line (SDSL) is another emerging technology, already available in the US, which has not been considered by this study. It supports E1 data rates using a single pair over distances of up to 10 km. The cumulative emissions model should be extended to include this technology.

12.2 Near Field Interference

- The near field emissions from xDSL technologies are potentially much higher than the cumulative far field emissions. The possibility of interference to MF radio services from xDSL emissions within the same building should be assessed.

12.3 Cumulative Space-Wave Emissions and Aeronautical Radio Systems

- The effect of cumulative emissions from space-wave fields above urban areas has been identified as a potential threat to certain aeronautical radio services. A model for the prediction of the space-wave fields should be developed.
- Details of the operational characteristics of both existing and proposed aeronautical communication and radio navigation systems should be determined. This will allow an assessment of the vulnerability of the system to interference from xDSL technologies to be made once the level of space-wave emissions is estimated.

12.4 PLT Systems

- The active spreadsheet for ground-wave emissions should be extended to cover PLT systems .
- Overhead power distribution is used in rural areas and also in other countries. This has not being addressed by this study. Given the demonstrated long range effects of skywave emissions the potential penetration of PLT technology on this type distribution system throughout Europe should be determined and a model of the cumulative emissions constructed.
- The radiative efficiency of the mains network in various types of building should be measured to validate the launch models in the PLT cumulative emissions predictions.

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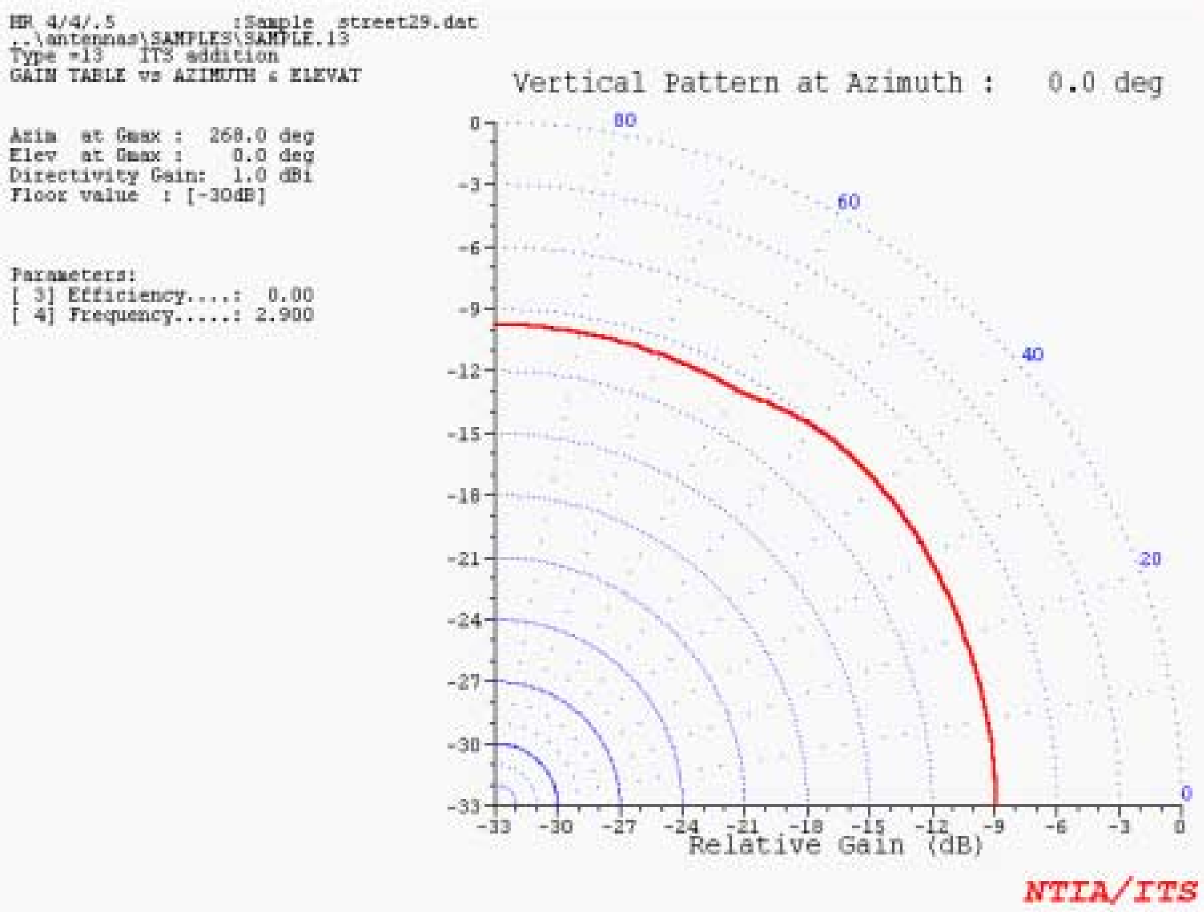
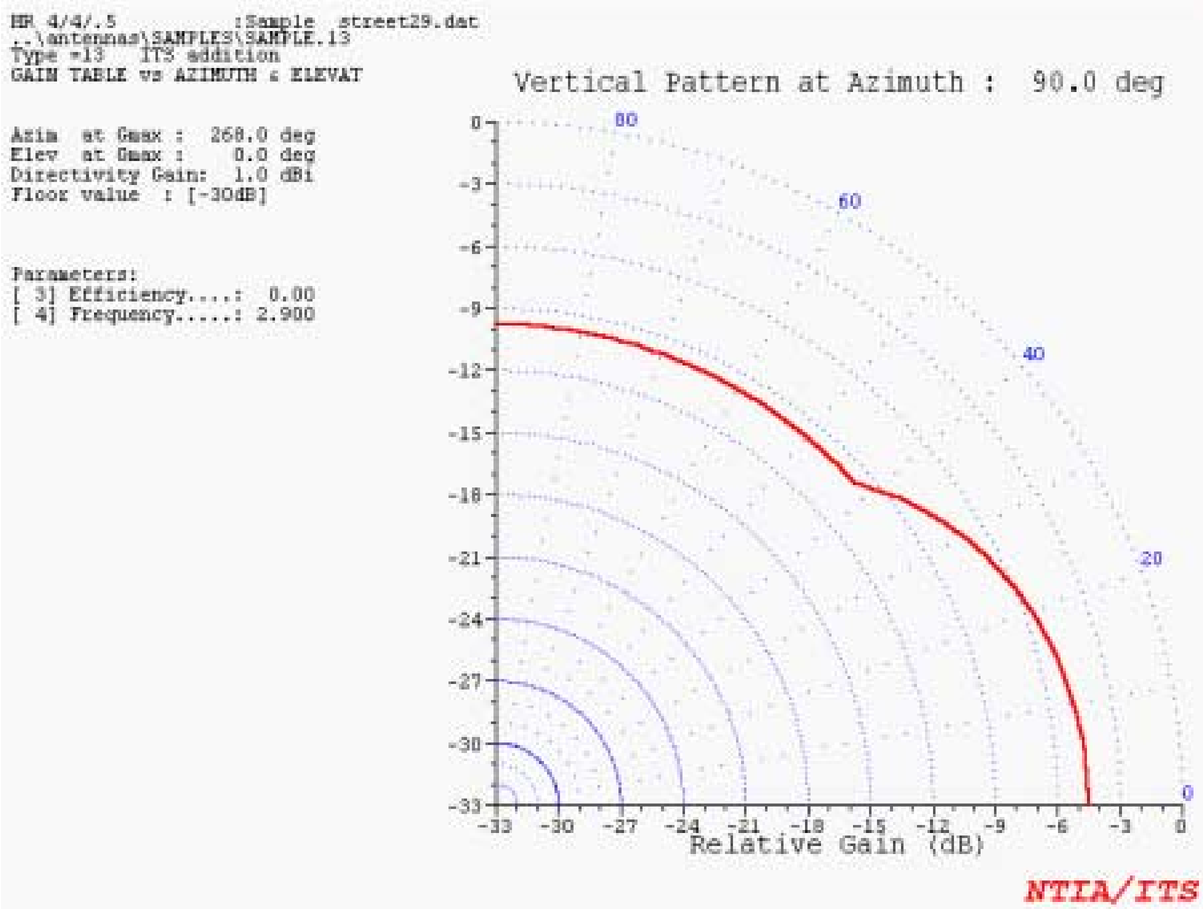
APPENDIX 1 PLT ANTENNAS IN CROSS SECTION

A1.1 Short street with lossy ground at 2.9MHz

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Elev at Gmax : 0.0 deg
Directivity Gain: 1.0 dBi
Floor value : [-30dB]
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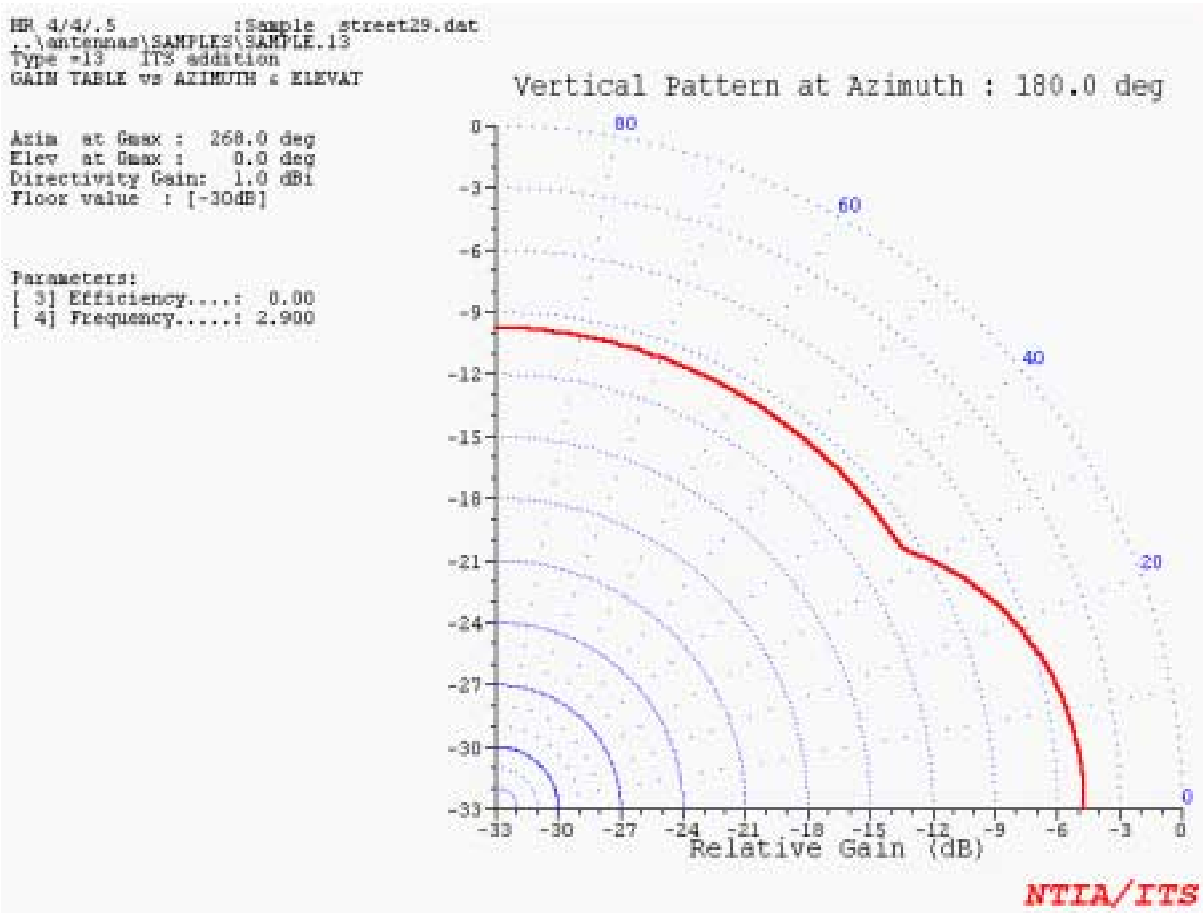
[3] Efficiency....: 0.00
[4] Frequency.....: 2.900
Vertical Pattern at Azimuth : 90.0 deg
Relative Gain (dB)
NTIA/ITS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Elev at Gmax : 0.0 deg
Directivity Gain: 1.0 dBi
Floor value : [-30dB]
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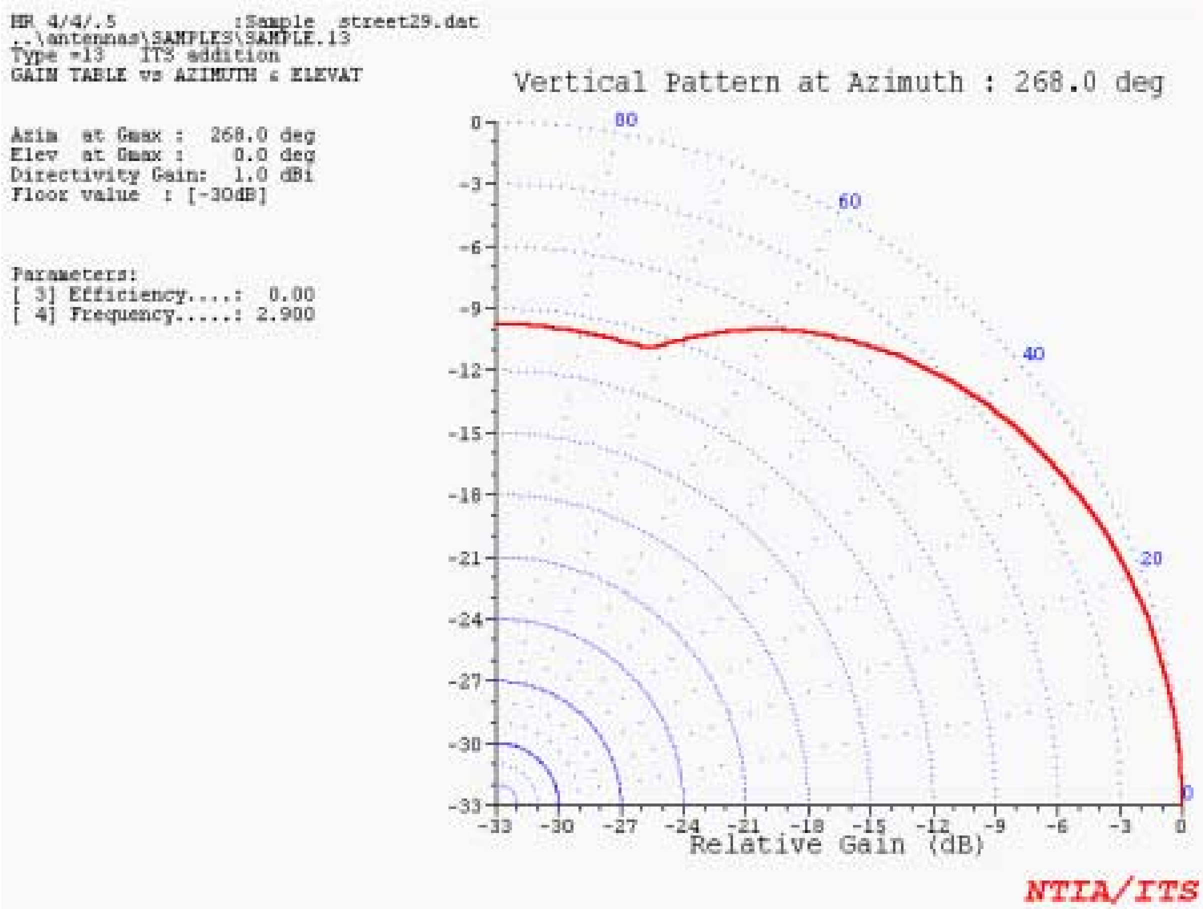
[3] Efficiency....: 0.00
[4] Frequency.....: 2.900
Vertical Pattern at Azimuth : 180.0 deg
Relative Gain (dB)
NTIA/ITS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Elev at Gmax : 0.0 deg
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Floor value : [-30dB]
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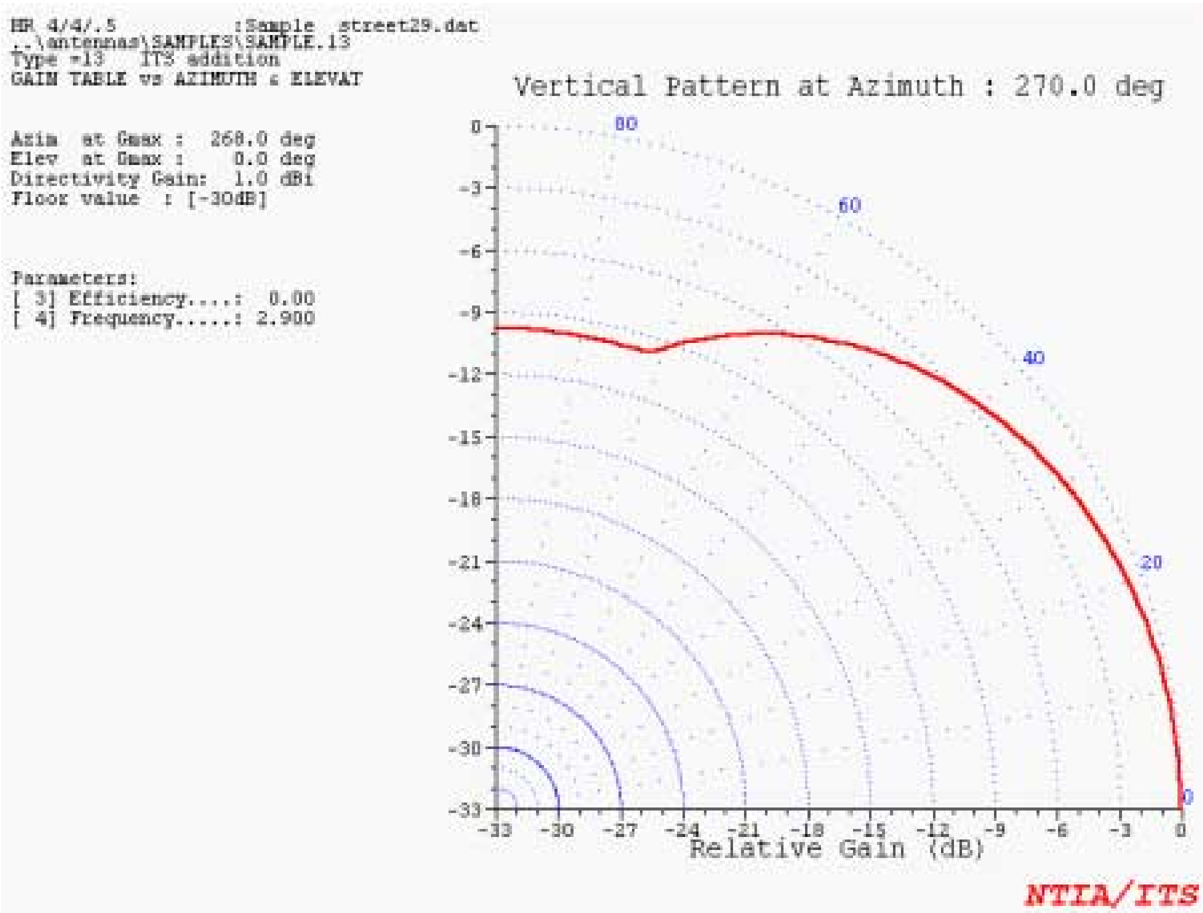
[4] Frequency.....: 2.900
Vertical Pattern at Azimuth : 268.0 deg
Relative Gain (dB)
NTIA/ITS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Elev at Gmax : 0.0 deg
Directivity Gain: 1.0 dBi
Floor value : [-30dB]
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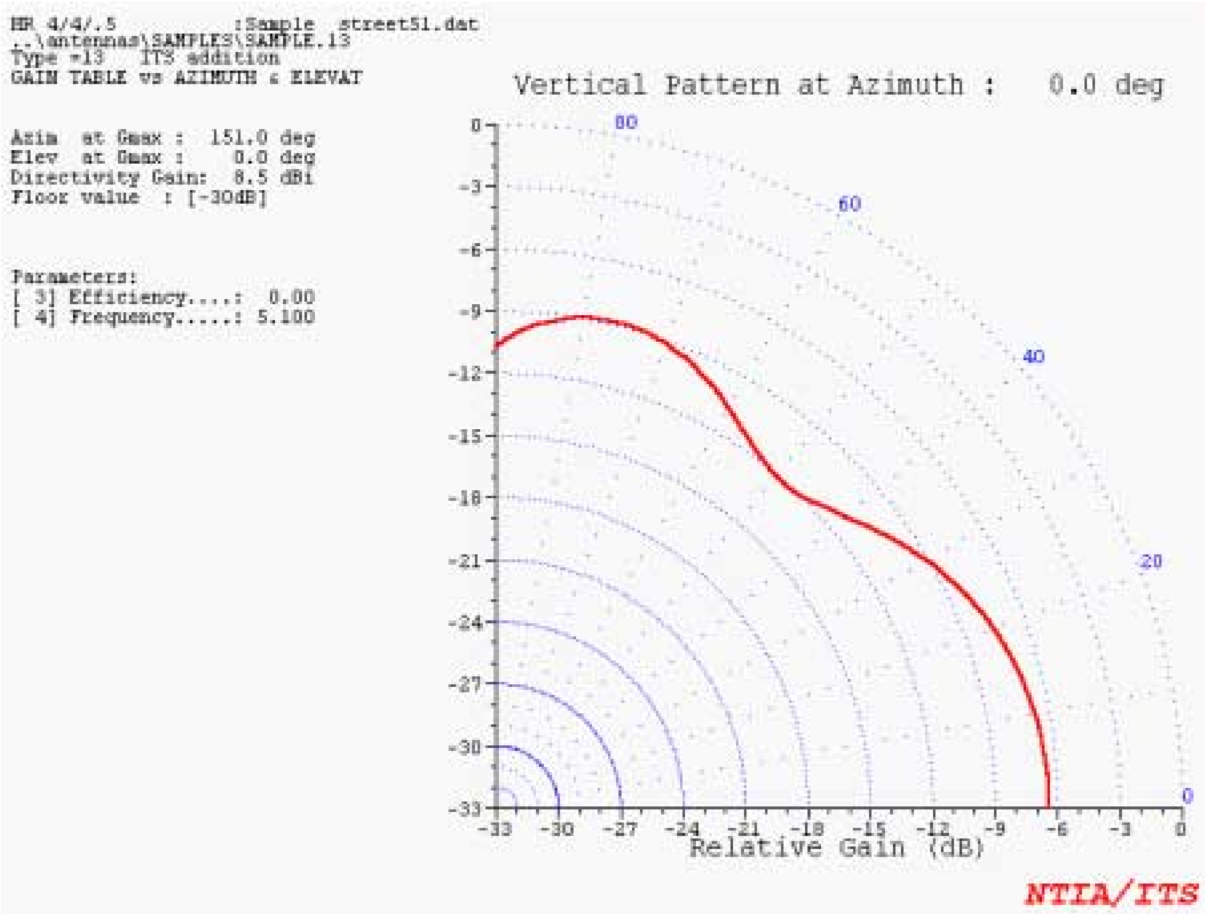
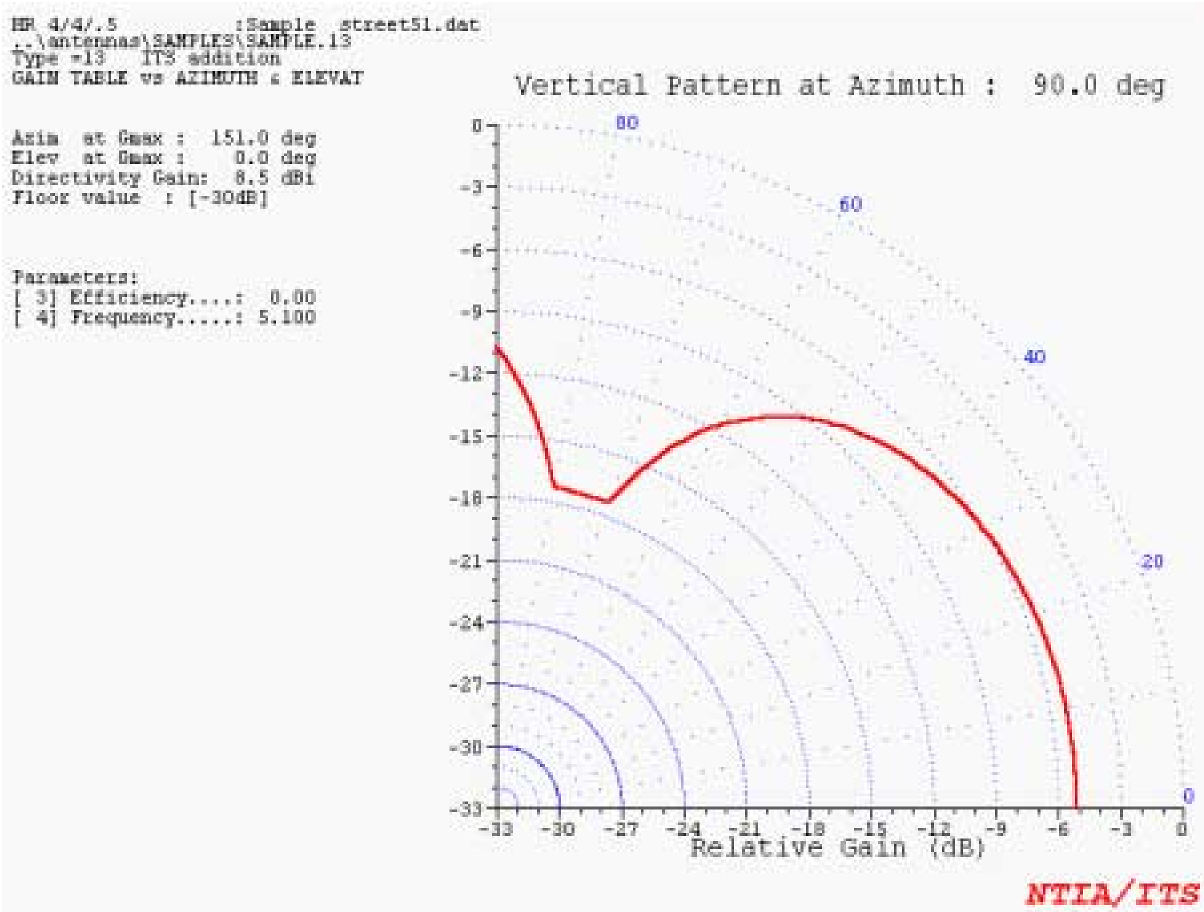
[3] Efficiency....: 0.00
[4] Frequency.....: 2.900
Vertical Pattern at Azimuth : 270.0 deg
Relative Gain (dB)
NTIA/ITS

A1.2 Short street with lossy ground at 5.1MHz

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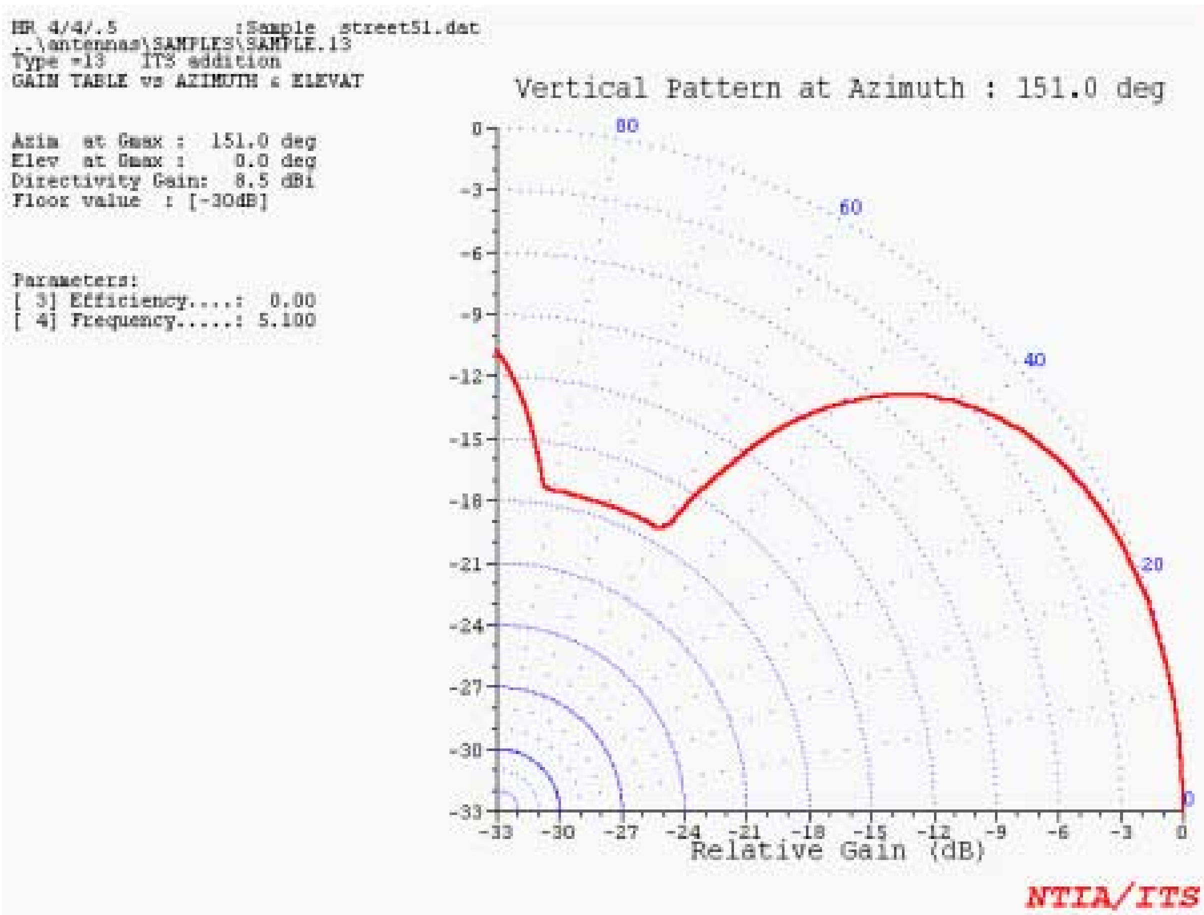
Elev at Gmax : 0.0 deg
Directivity Gain: 8.5 dBi
Floor value : [-30dB]
Parameters:
[3] Efficiency....: 0.00
[4] Frequency.....: 5.100
Vertical Pattern at Azimuth : 90.0 deg
80
60
40
20
0
0
-3
-6
-9
-12
-15
-18
-21
-24
-27
-30
-33
-33 -30 -27 -24 -21 -18 -15 -12 -9 -6 -3 0
Relative Gain (dB)
NTIA/ITS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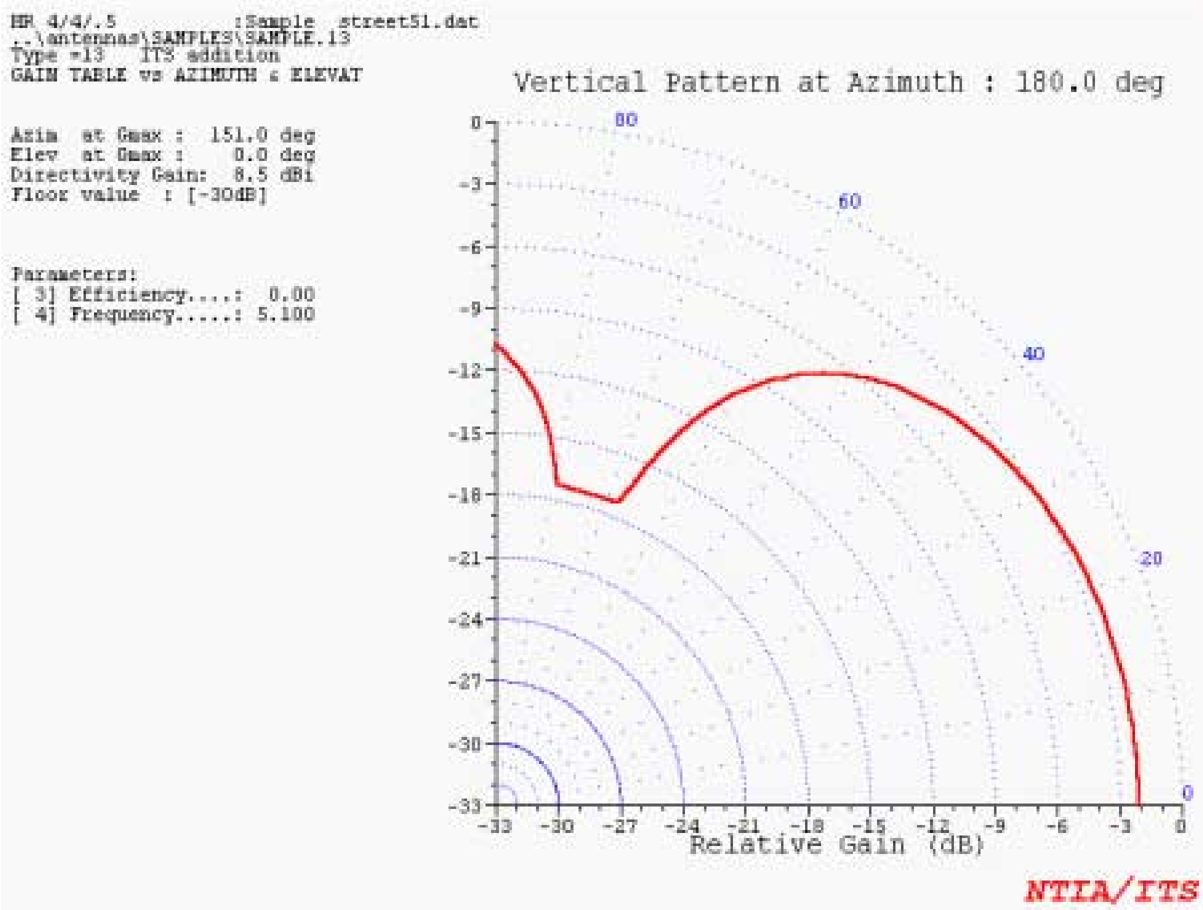
Elev at Gmax : 0.0 deg
Directivity Gain: 8.5 dBi
Floor value : [-30dB]
Parameters:
[3] Efficiency....: 0.00
[4] Frequency.....: 5.100
Vertical Pattern at Azimuth : 151.0 deg
80
60
40
20
0
0
-3
-6
-9
-12
-15
-18
-21
-24
-27
-30
-33
-33 -30 -27 -24 -21 -18 -15 -12 -9 -6 -3 0
Relative Gain (dB)
NTIA/ITS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Directivity Gain: 8.5 dBi
Floor value : [-30dB]
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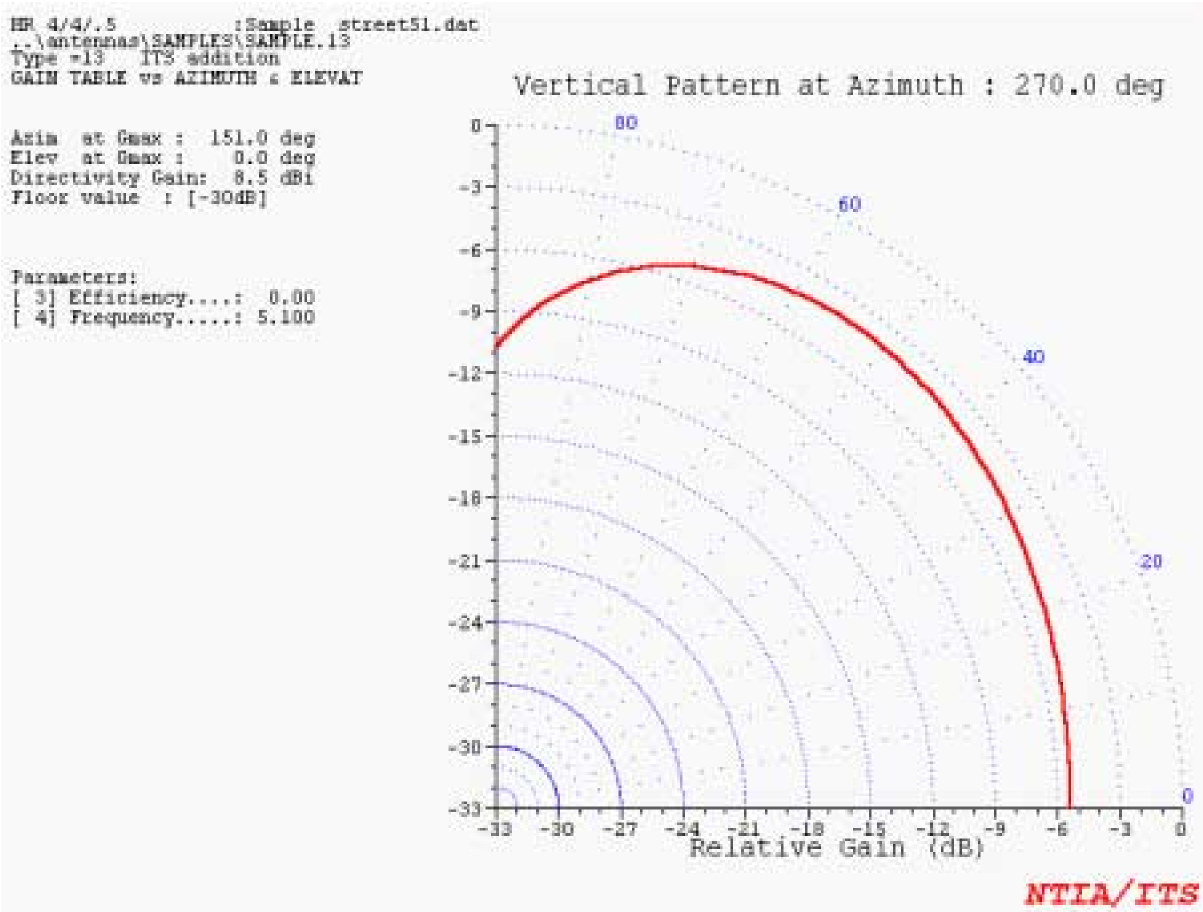
[4] Frequency.....: 5.100
Vertical Pattern at Azimuth : 180.0 deg
Relative Gain (dB)
NTIA/ITS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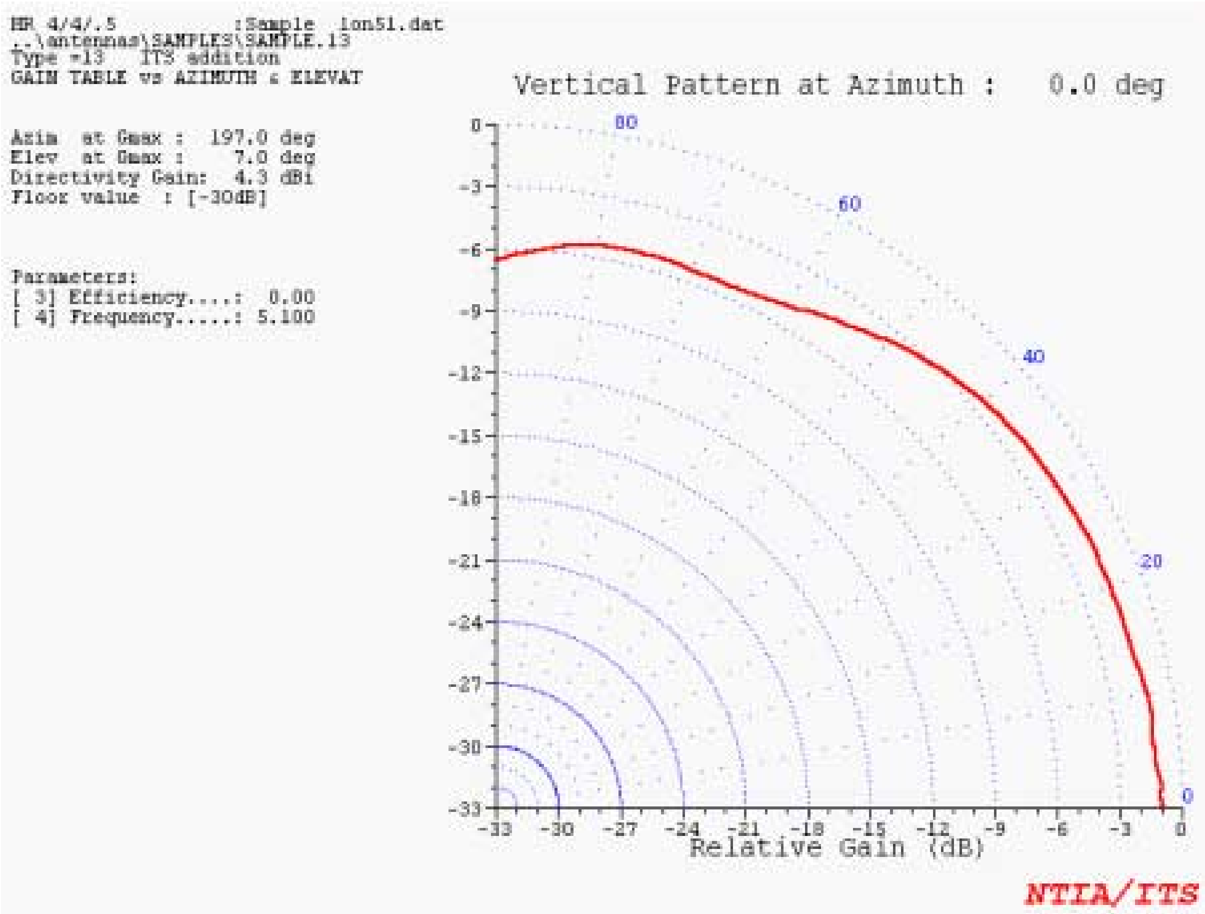
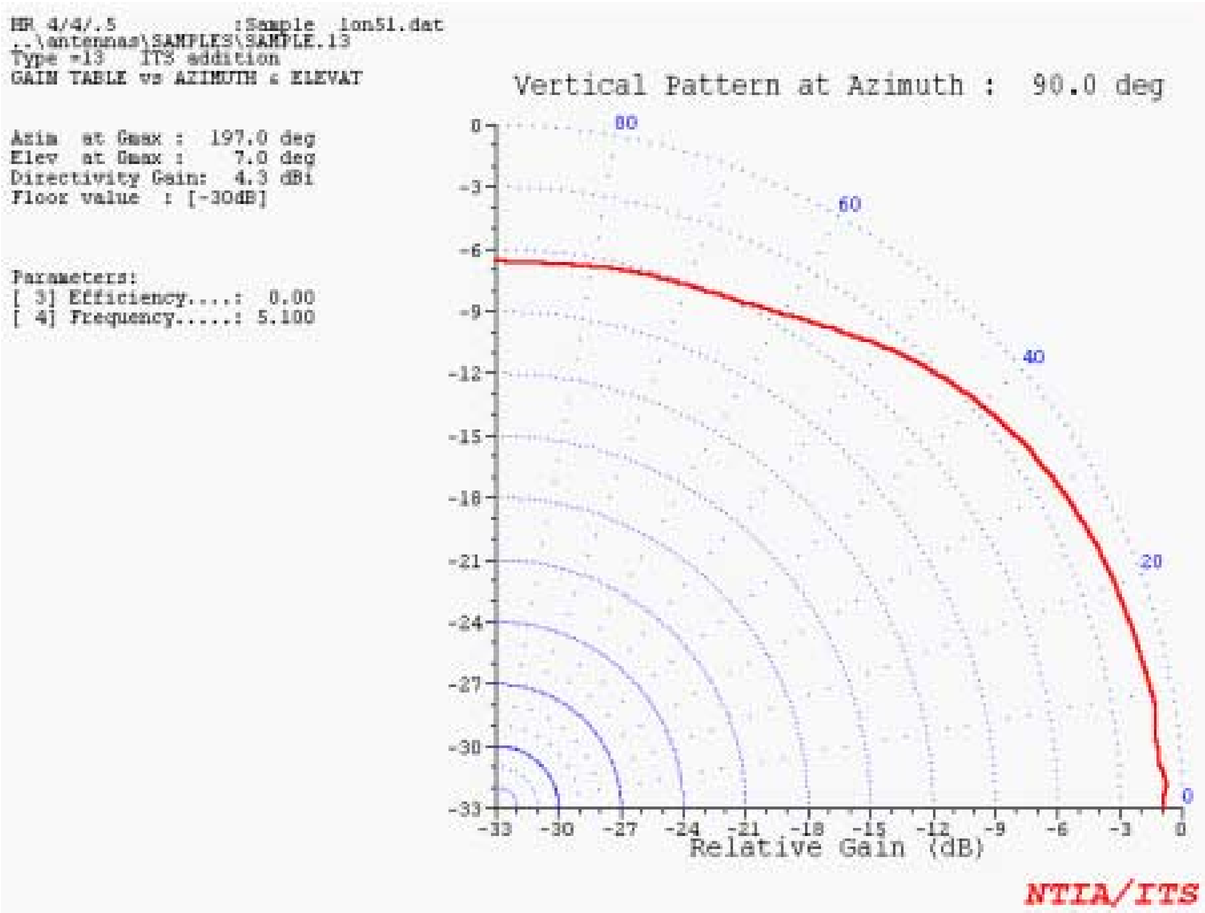
Elev at Gmax : 0.0 deg
Directivity Gain: 8.5 dBi
Floor value : [-30dB]
Parameters:
[3] Efficiency....: 0.00
[4] Frequency.....: 5.100
Vertical Pattern at Azimuth : 270.0 deg
Relative Gain (dB)
NTIA/ITS

A1.3 Cumulative London antenna at 5.1MHz

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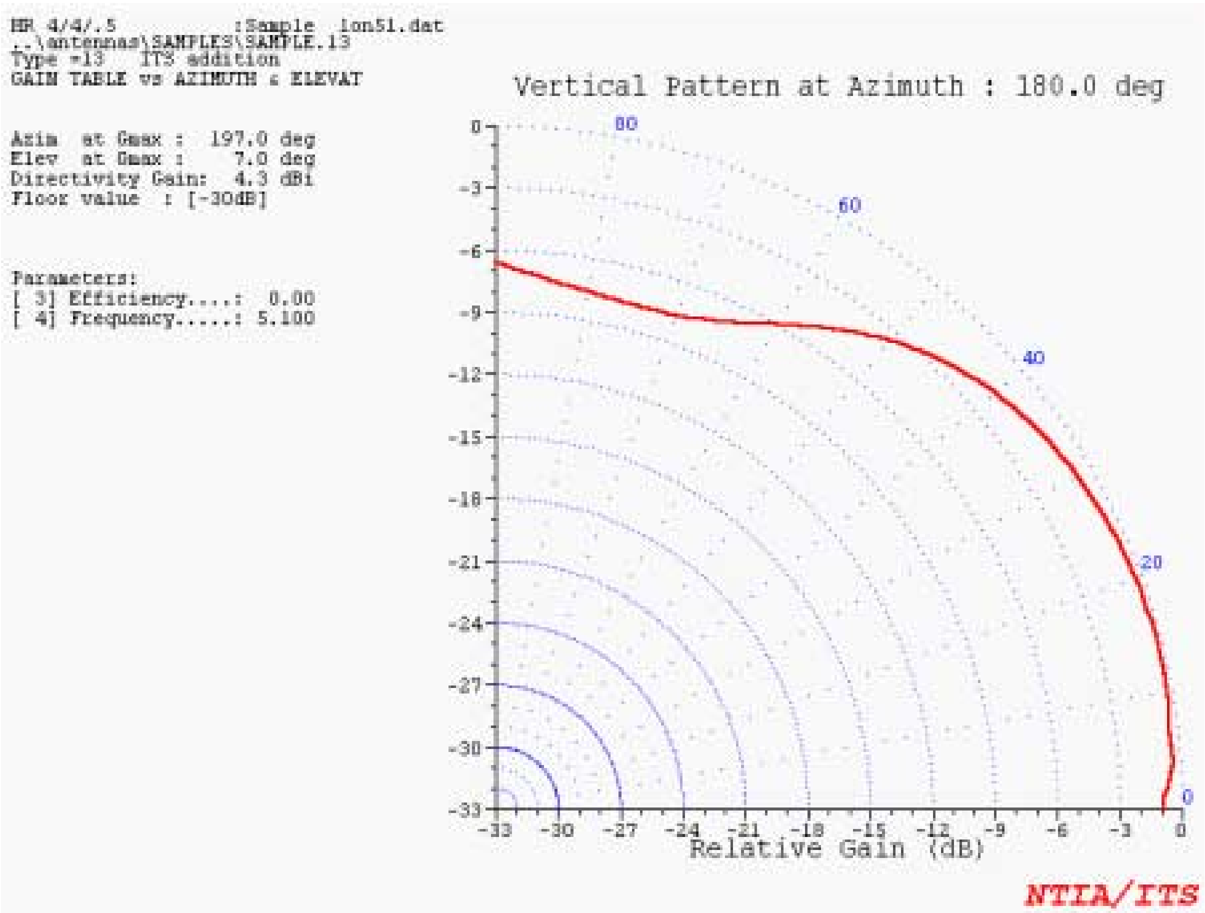
Azim at Gmax : 197.0 deg
Elev at Gmax : 7.0 deg
Directivity Gain: 4.3 dBi
Floor value : [-30dB]
Parameters:
[3] Efficiency....: 0.00
[4] Frequency.....: 5.100
Vertical Pattern at Azimuth : 90.0 deg
Relative Gain (dB)
NTIA/ITS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Elev at Gmax : 7.0 deg
Directivity Gain: 4.3 dBi
Floor value : [-30dB]
Parameters:
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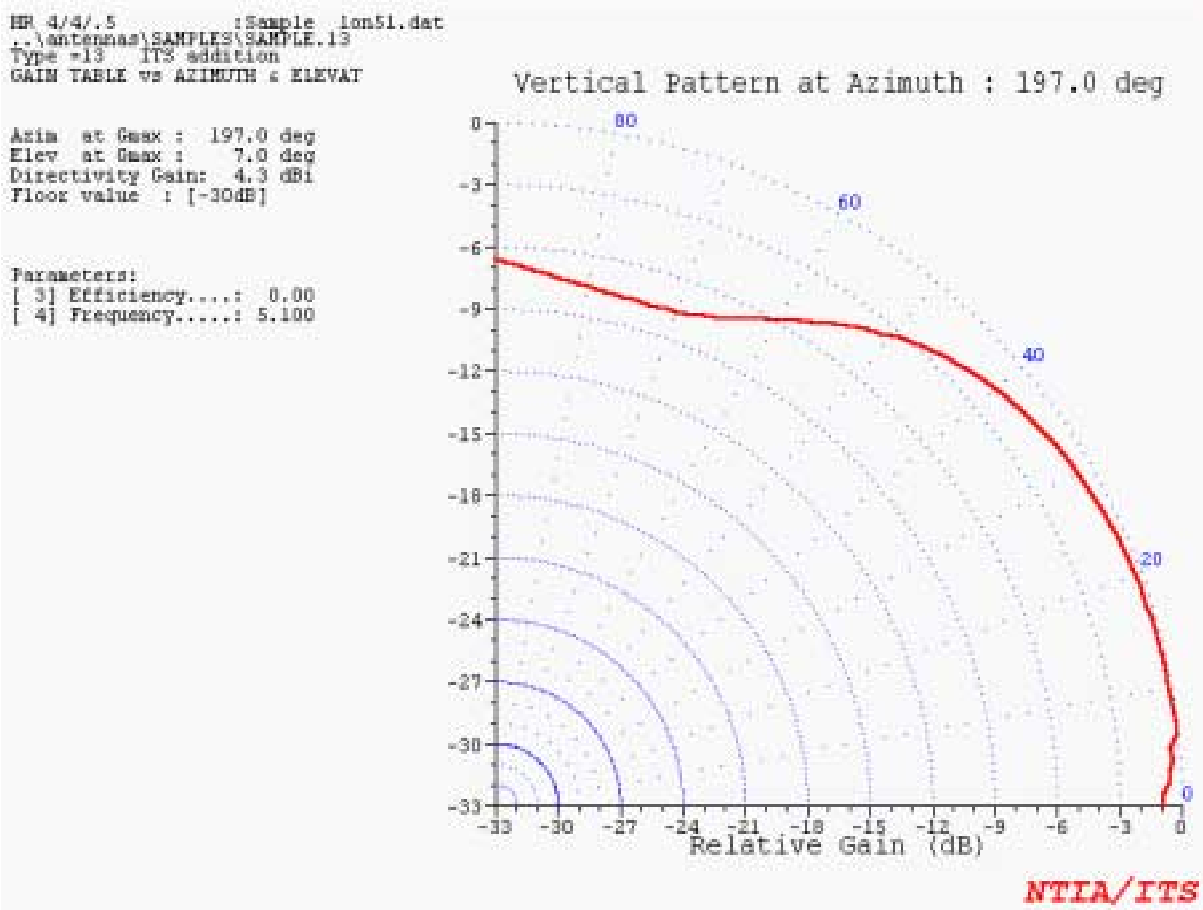
[4] Frequency.....: 5.100
Vertical Pattern at Azimuth : 180.0 deg
Relative Gain (dB)
NTIA/ITS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Floor value : [-30dB]
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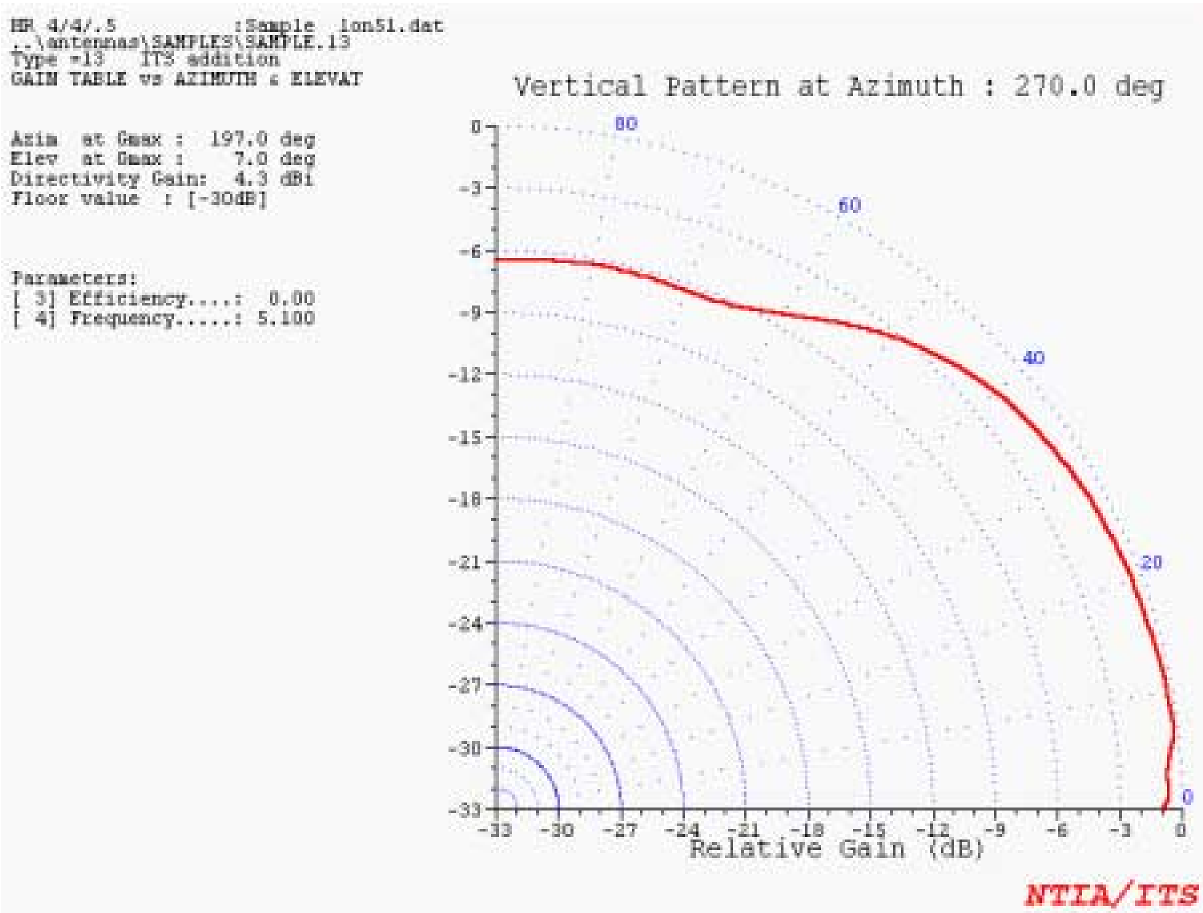
[4] Frequency.....: 5.100
Vertical Pattern at Azimuth : 197.0 deg
Relative Gain (dB)
NTIA/ITS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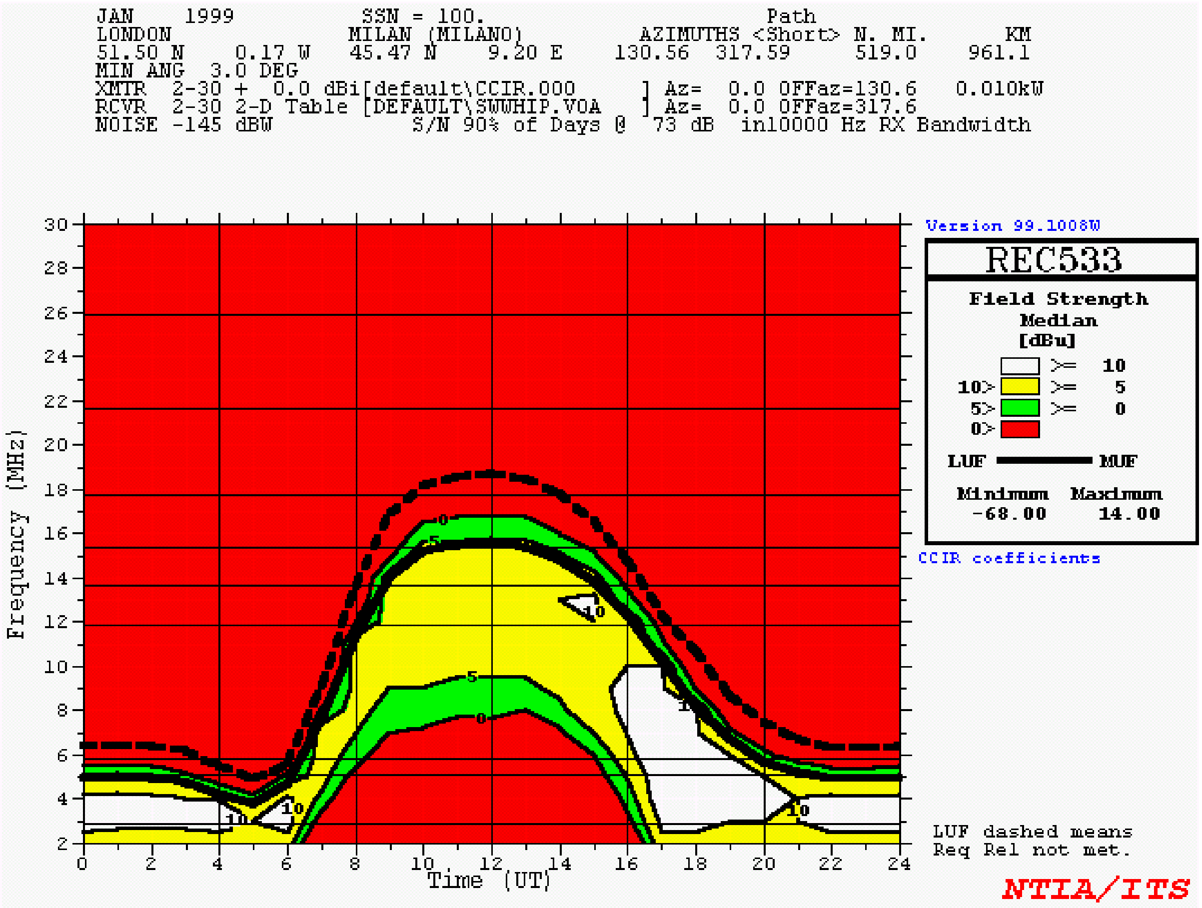
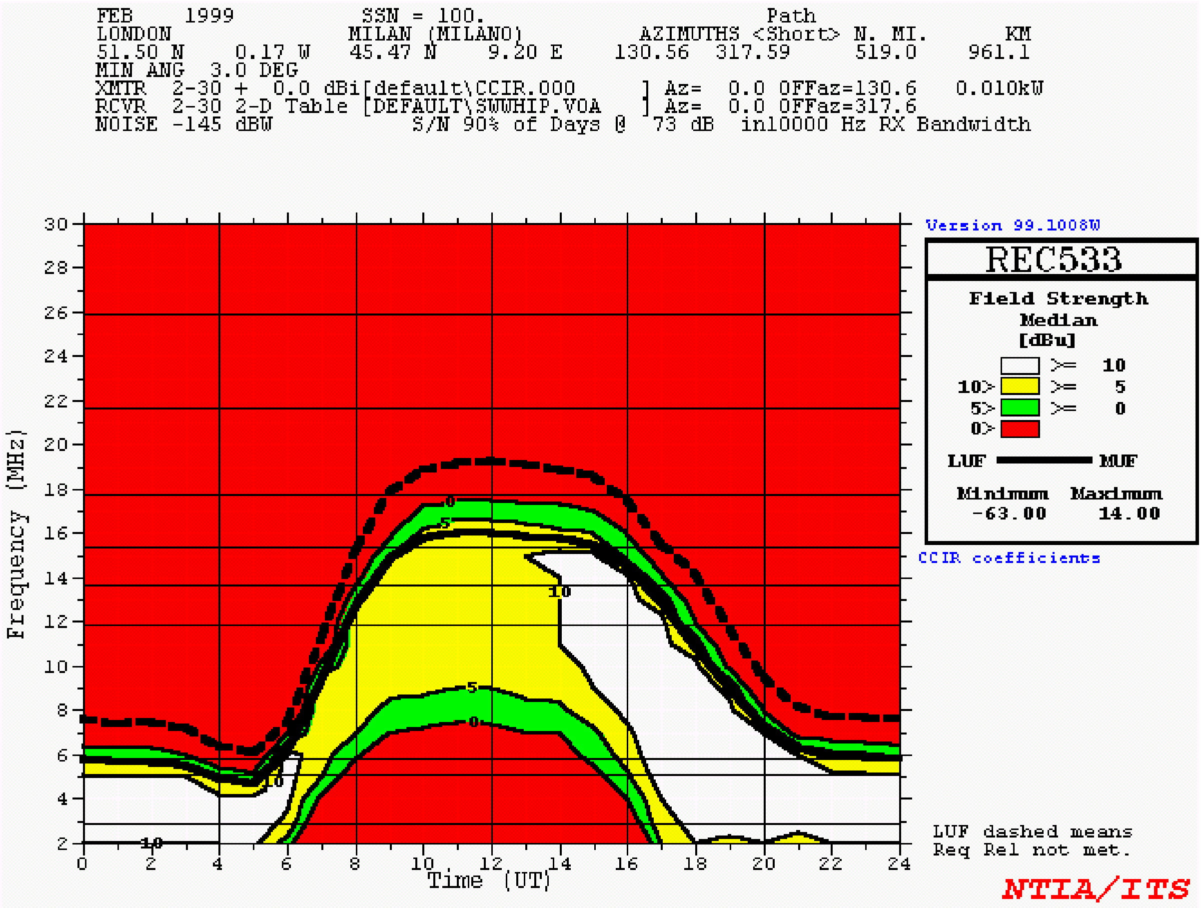
Azim at Gmax : 197.0 deg
Elev at Gmax : 7.0 deg
Directivity Gain: 4.3 dBi
Floor value : [-30dB]
Parameters:
[3] Efficiency....: 0.00
[4] Frequency.....: 5.100
Vertical Pattern at Azimuth : 270.0 deg
Relative Gain (dB)
NTIA/ITS

APPENDIX 2 POINT TO POINT PLOTS TO DETERMINE WORST CASE MONTH

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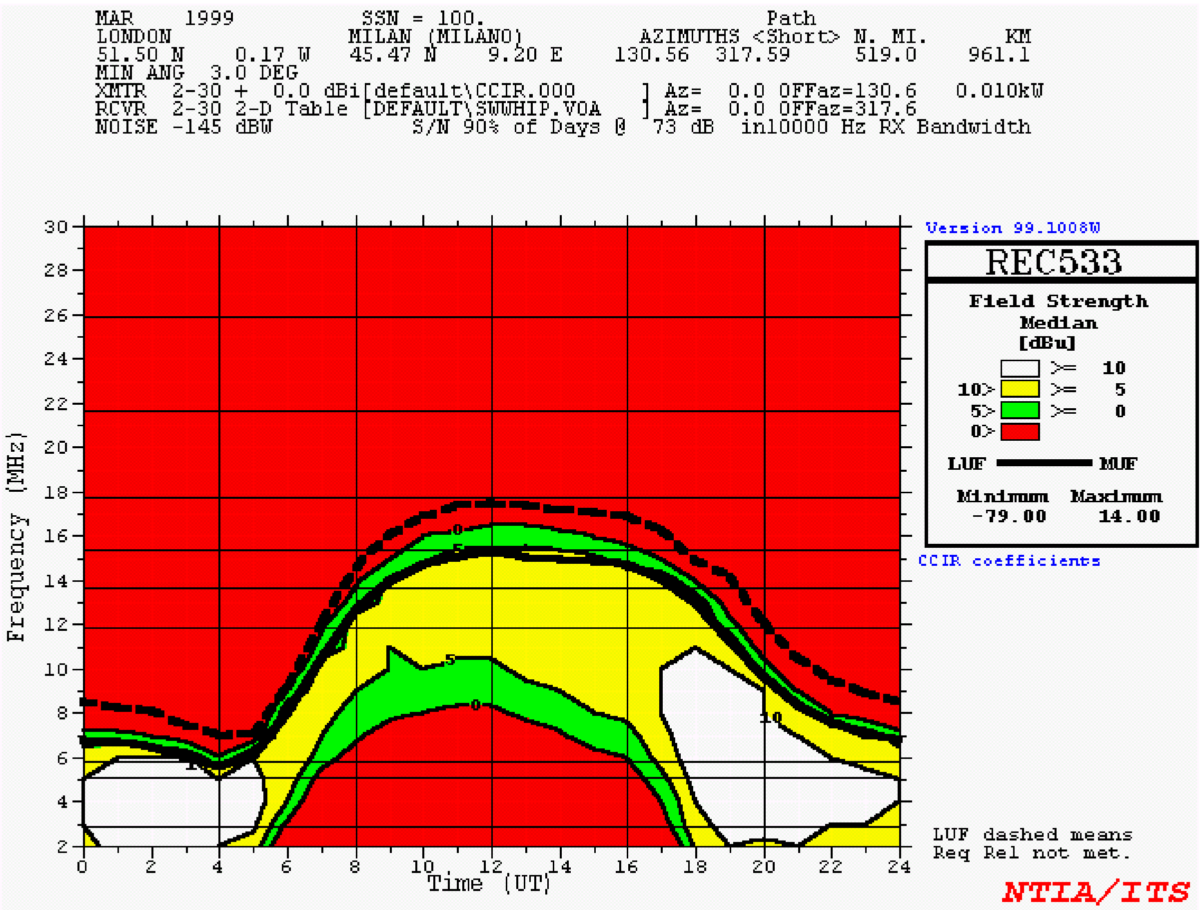
51.50 N 0.17 W 45.47 N 9.20 E 130.56 317.59 519.0 961.1
MIN ANG 3.0 DEG
XMTR 2-30 + 0.0 dBi[default\CCIR.000] Az= 0.0 OFFaz=130.6 0.010kW
RCVR 2-30 2-D Table [DEFAULT\SWWHIP.VOA] Az= 0.0 OFFaz=317.6
NOISE -145 dBW S/N 90% of Days @ 73 dB in10000 Hz RX Bandwidth
Frequency (MHz)
Time (UT)
Version 99.1008W
REC533
Field Strength
Median
[dBu]
>= 10
10> >= 5
5> >= 0
0>
LUF MUF
Minimum Maximum
-63.00 14.00
CCIR coefficients
LUF dashed means
Req Rel not met.
NTIA/ITS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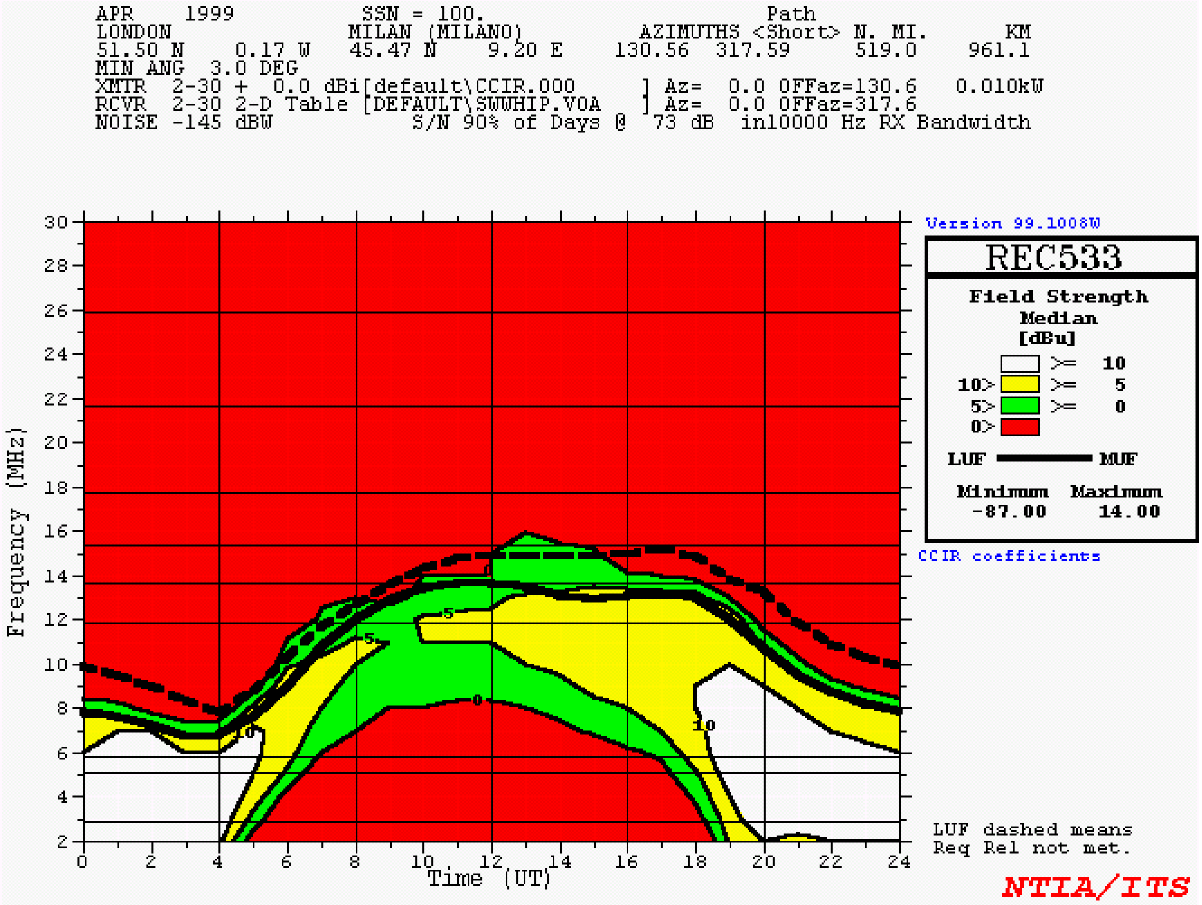
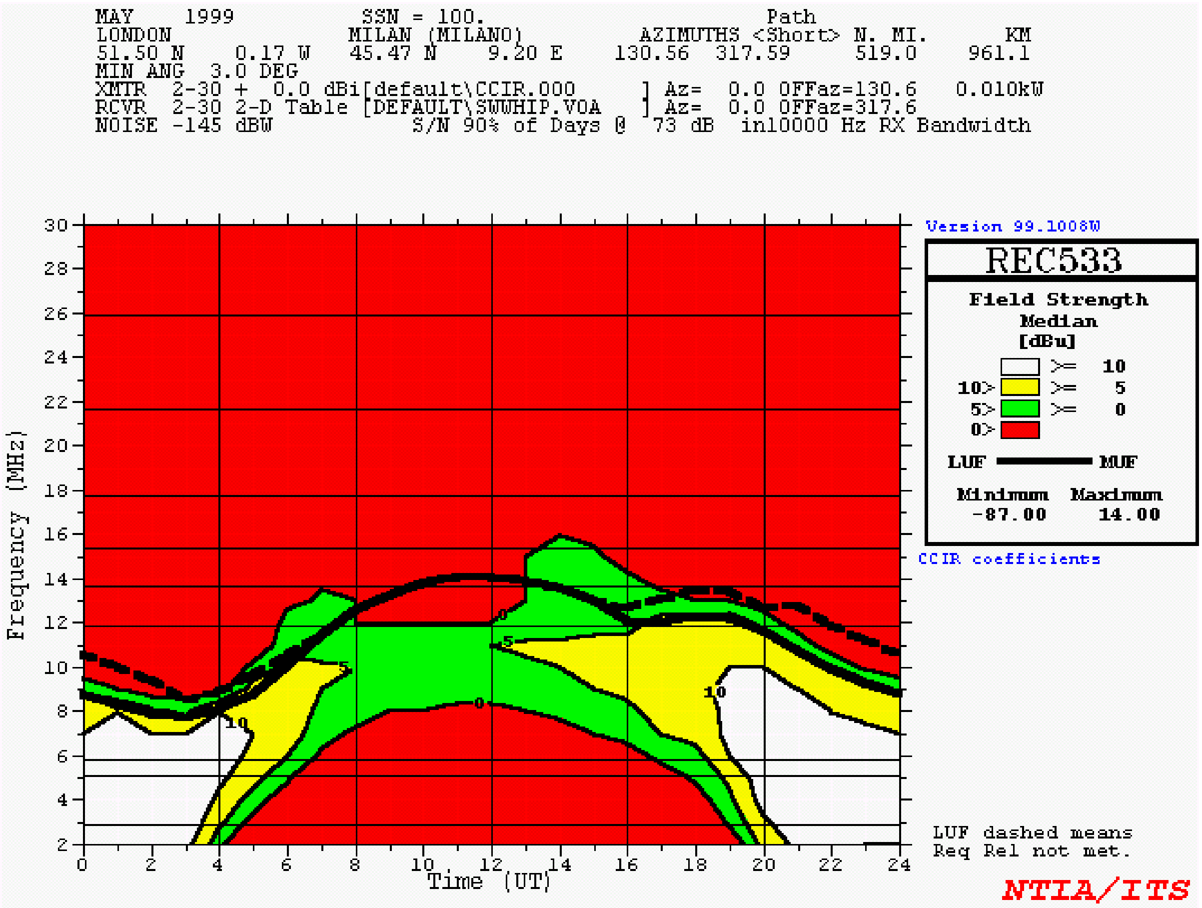
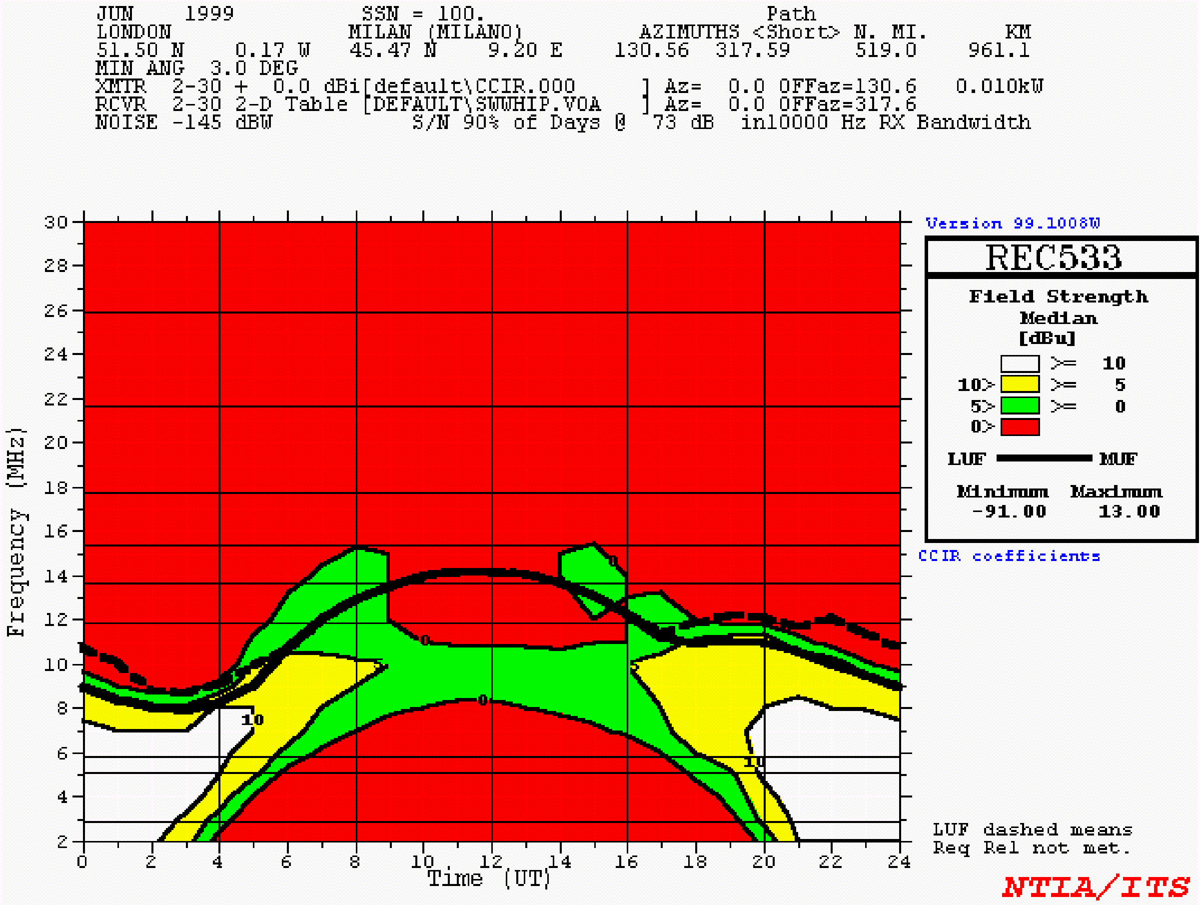
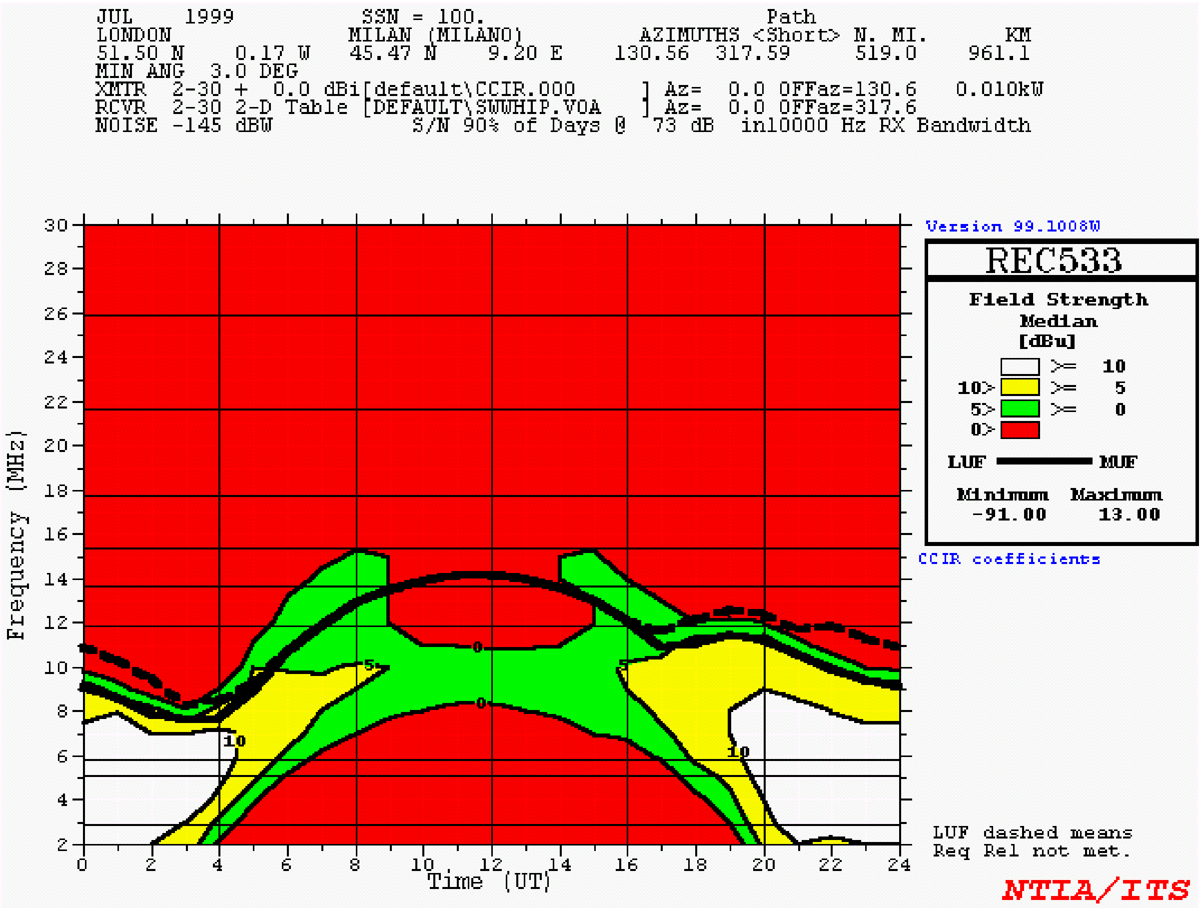
51.50 N 0.17 W 45.47 N 9.20 E 130.56 317.59 519.0 961.1
MIN ANG 3.0 DEG
XMTR 2-30 + 0.0 dBi[default\CCIR.000] Az= 0.0 OFFaz=130.6 0.010kW
RCVR 2-30 2-D Table [DEFAULT\SWWHIP.VOA] Az= 0.0 OFFaz=317.6
NOISE -145 dBW S/N 90% of Days @ 73 dB in10000 Hz RX Bandwidth
Frequency (MHz)
Time (UT)
Version 99.1008W
REC533
Field Strength
Median
[dBu]
>= 10
10> >= 5
5> >= 0
0>
LUF MUF
Minimum Maximum
-79.00 14.00
CCIR coefficients
LUF dashed means
Req Rel not met.
NTIA/ITS

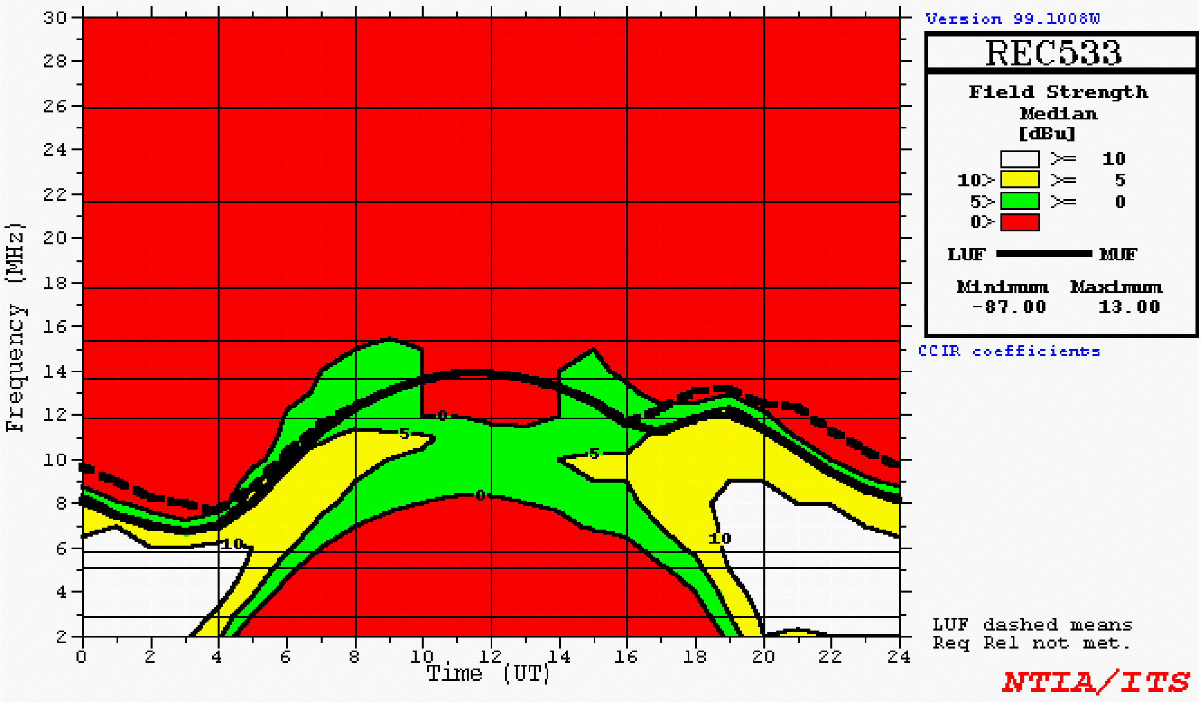

APR 1999 SSN = 100. Path
LONDON MILAN (MILANO) AZIMUTHS <Short> N. MI. KM
51.50 N 0.17 W 45.47 N 9.20 E 130.56 317.59 519.0 961.1
MIN ANG 3.0 DEG
XMTR 2-30 + 0.0 dBi[default\CCIR.000] Az= 0.0 OFFaz=130.6 0.010kW
RCVR 2-30 2-D Table [DEFAULT\SWWHIP.VOA] Az= 0.0 OFFaz=317.6
NOISE -145 dBW S/N 90% of Days @ 73 dB in10000 Hz RX Bandwidth
Version 99.1008W
REC533
Field Strength
Median
[dBu]
>= 10
10> >= 5
5> >= 0
0>
LUF MUF
Minimum Maximum
-87.00 14.00
CCIR coefficients
Frequency (MHz)
Time (UT)
LUF dashed means
Req Rel not met.
NTIA/ITS


MAY 1999 SSN = 100. Path
LONDON MILAN (MILANO) AZIMUTHS <Short> N. MI. KM
51.50 N 0.17 W 45.47 N 9.20 E 130.56 317.59 519.0 961.1
MIN ANG 3.0 DEG
XMTR 2-30 + 0.0 dBi[default\CCIR.000] Az= 0.0 OFFaz=130.6 0.010kW
RCVR 2-30 2-D Table [DEFAULT\SWWHIP.VOA] Az= 0.0 OFFaz=317.6
NOISE -145 dBW S/N 90% of Days @ 73 dB in10000 Hz RX Bandwidth
Version 99.1008W
REC533
Field Strength
Median
[dBu]
>= 10
10> >= 5
5> >= 0
0>
LUF MUF
Minimum Maximum
-87.00 14.00
CCIR coefficients
Frequency (MHz)
Time (UT)
LUF dashed means
Req Rel not met.
NTIA/ITS

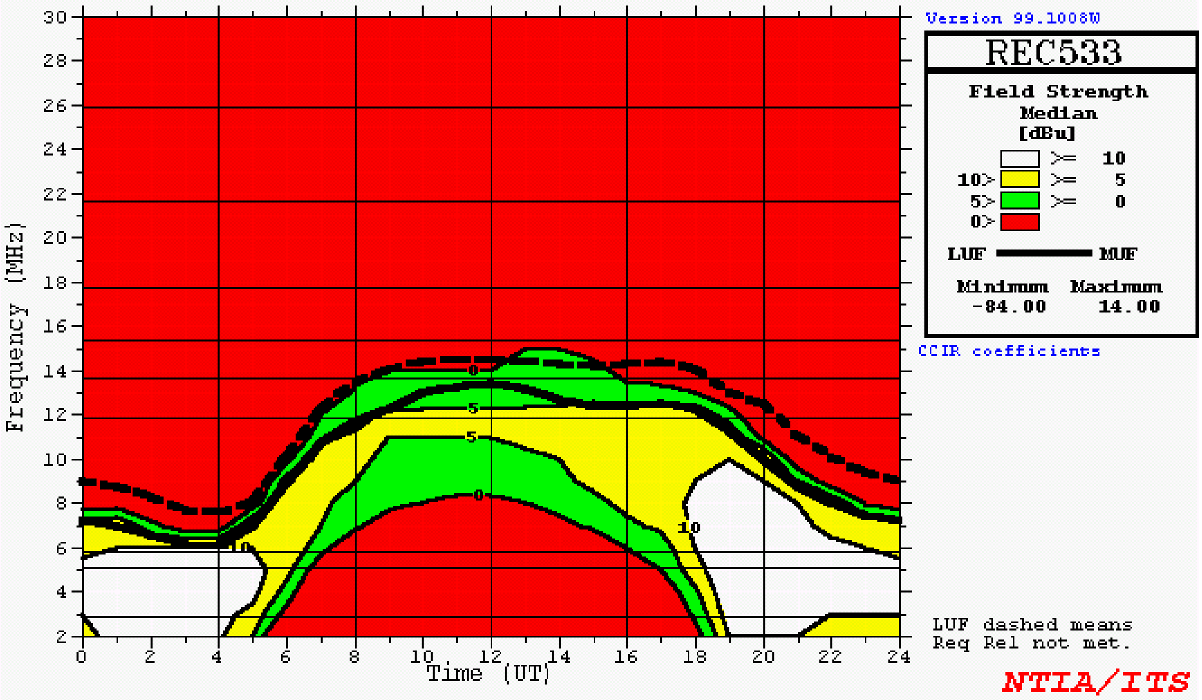

JUN 1999 SSN = 100. Path
LONDON MILAN (MILANO) AZIMUTHS <Short> N. MI. KM
51.50 N 0.17 W 45.47 N 9.20 E 130.56 317.59 519.0 961.1
MIN ANG 3.0 DEG
XMTR 2-30 + 0.0 dBi[default\CCIR.000] Az= 0.0 OFFaz=130.6 0.010kW
RCVR 2-30 2-D Table [DEFAULT\SWWHIP.VOA] Az= 0.0 OFFaz=317.6
NOISE -145 dBW S/N 90% of Days @ 73 dB in10000 Hz RX Bandwidth
Frequency (MHz)
Time (UT)
Version 99.1008W
REC533
Field Strength
Median
[dBu]
>= 10
10> >= 5
5> >= 0
0>
LUF MUF
Minimum Maximum
-91.00 13.00
CCIR coefficients
LUF dashed means
Req Rel not met.
NTIA/ITS

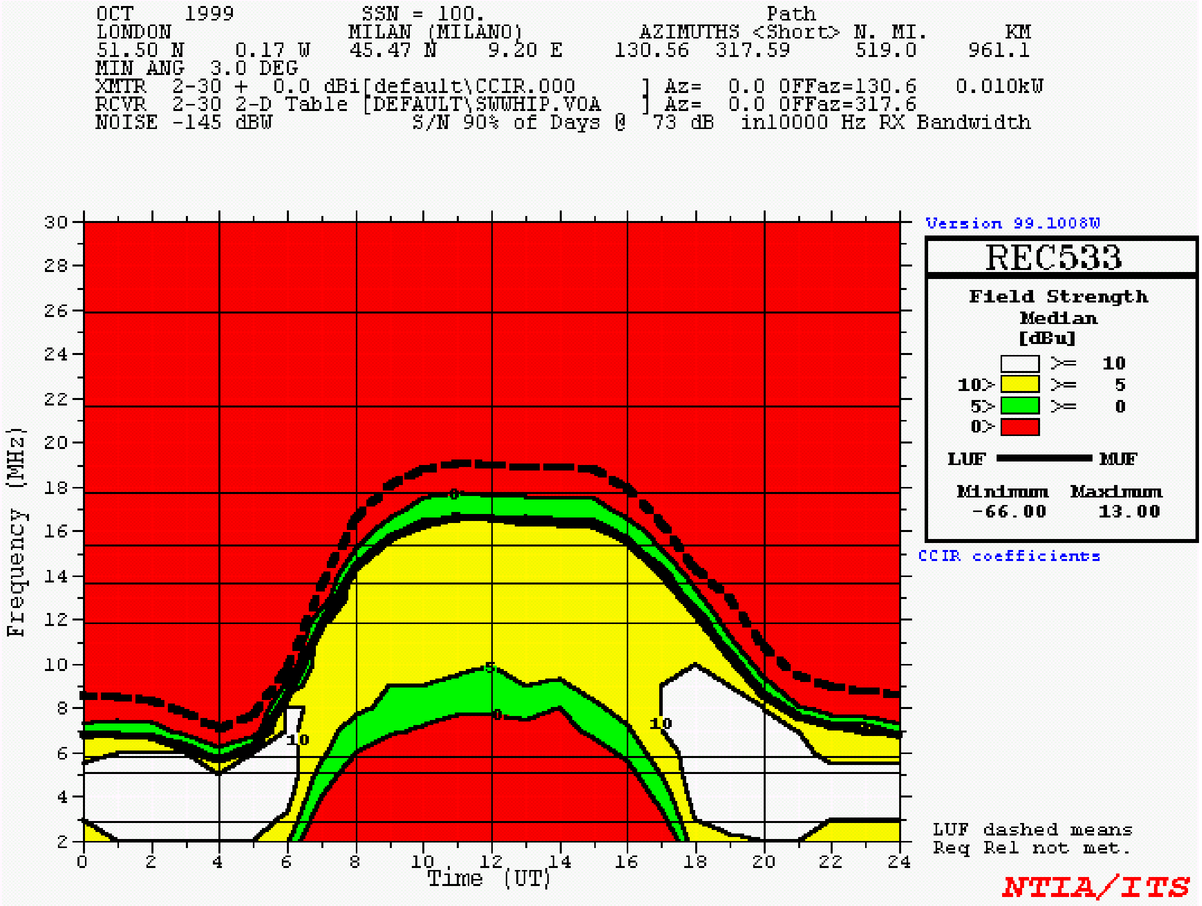

JUL 1999 SSN = 100. Path
LONDON MILAN (MILANO) AZIMUTHS <Short> N. MI. KM
51.50 N 0.17 W 45.47 N 9.20 E 130.56 317.59 519.0 961.1
MIN ANG 3.0 DEG
XMTR 2-30 + 0.0 dBi[default\CCIR.000] Az= 0.0 OFFaz=130.6 0.010kW
RCVR 2-30 2-D Table [DEFAULT\SWWHIP.VOA] Az= 0.0 OFFaz=317.6
NOISE -145 dBW S/N 90% of Days @ 73 dB in10000 Hz RX Bandwidth
Frequency (MHz)
Time (UT)
Version 99.1008W
REC533
Field Strength
Median
[dBu]
>= 10
10> >= 5
5> >= 0
0>
LUF MUF
Minimum Maximum
-91.00 13.00
CCIR coefficients
LUF dashed means
Req Rel not met.
NTIA/ITS

```
AUG     1999              SSN = 100.                     Path
LONDON                  MILAN (MILANO)          AZIMUTHS <Short> N. MI.      KM
51.50 N     0.17 W      45.47 N      9.20 E    130.56  317.59     519.0     961.1
MIN ANG   3.0 DEG
XMTR  2-30 +  0.0 dBi[default\CCIR.000      ] Az=  0.0 OFFaz=130.6    0.010kW
RCVR  2-30 2-D Table [DEFAULT\SWWHIP.VOA    ] Az=  0.0 OFFaz=317.6
NOISE -145 dBW              S/N 90% of Days @  73 dB  in10000 Hz RX Bandwidth
```

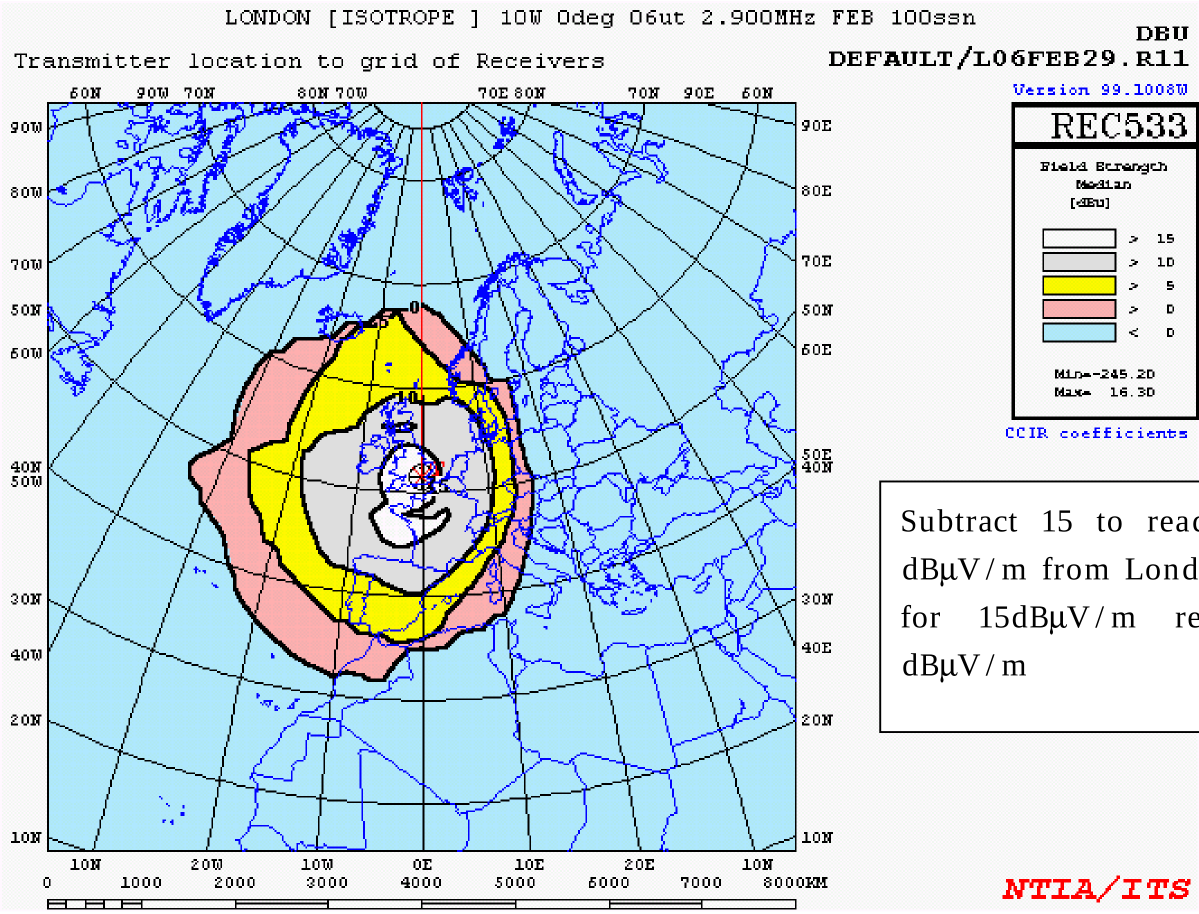



```
SEP     1999              SSN = 100.                     Path
LONDON                  MILAN (MILANO)          AZIMUTHS <Short> N. MI.      KM
51.50 N     0.17 W      45.47 N      9.20 E    130.56  317.59     519.0     961.1
MIN ANG   3.0 DEG
XMTR  2-30 +  0.0 dBi[default\CCIR.000      ] Az=  0.0 OFFaz=130.6    0.010kW
RCVR  2-30 2-D Table [DEFAULT\SWWHIP.VOA    ] Az=  0.0 OFFaz=317.6
NOISE -145 dBW              S/N 90% of Days @  73 dB  in10000 Hz RX Bandwidth
```

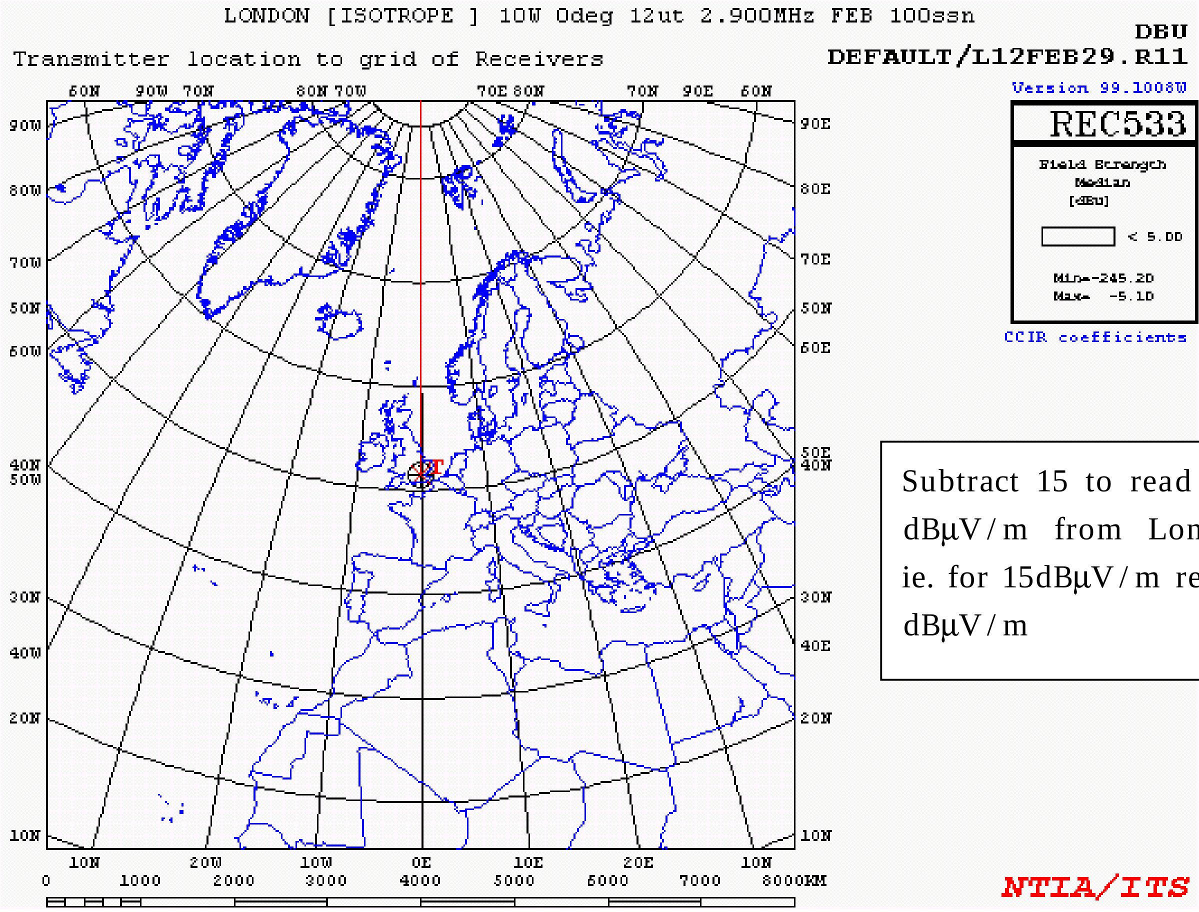



OCT 1999 SSN = 100. Path
LONDON MILAN (MILANO) AZIMUTHS <Short> N. MI. KM
51.50 N 0.17 W 45.47 N 9.20 E 130.56 317.59 519.0 961.1
MIN ANG 3.0 DEG
XMTR 2-30 + 0.0 dBi[default\CCIR.000] Az= 0.0 OFFaz=130.6 0.010kW
RCVR 2-30 2-D Table [DEFAULT\SWWHIP.VOA] Az= 0.0 OFFaz=317.6
NOISE -145 dBW S/N 90% of Days @ 73 dB in10000 Hz RX Bandwidth
Version 99.1008W
REC533
Field Strength
Median
[dBu]
>= 10
10> >= 5
5> >= 0
0>
LUF MUF
Minimum Maximum
-66.00 13.00
CCIR coefficients
Frequency (MHz)
Time (UT)
LUF dashed means
Req Rel not met.
NTIA/ITS

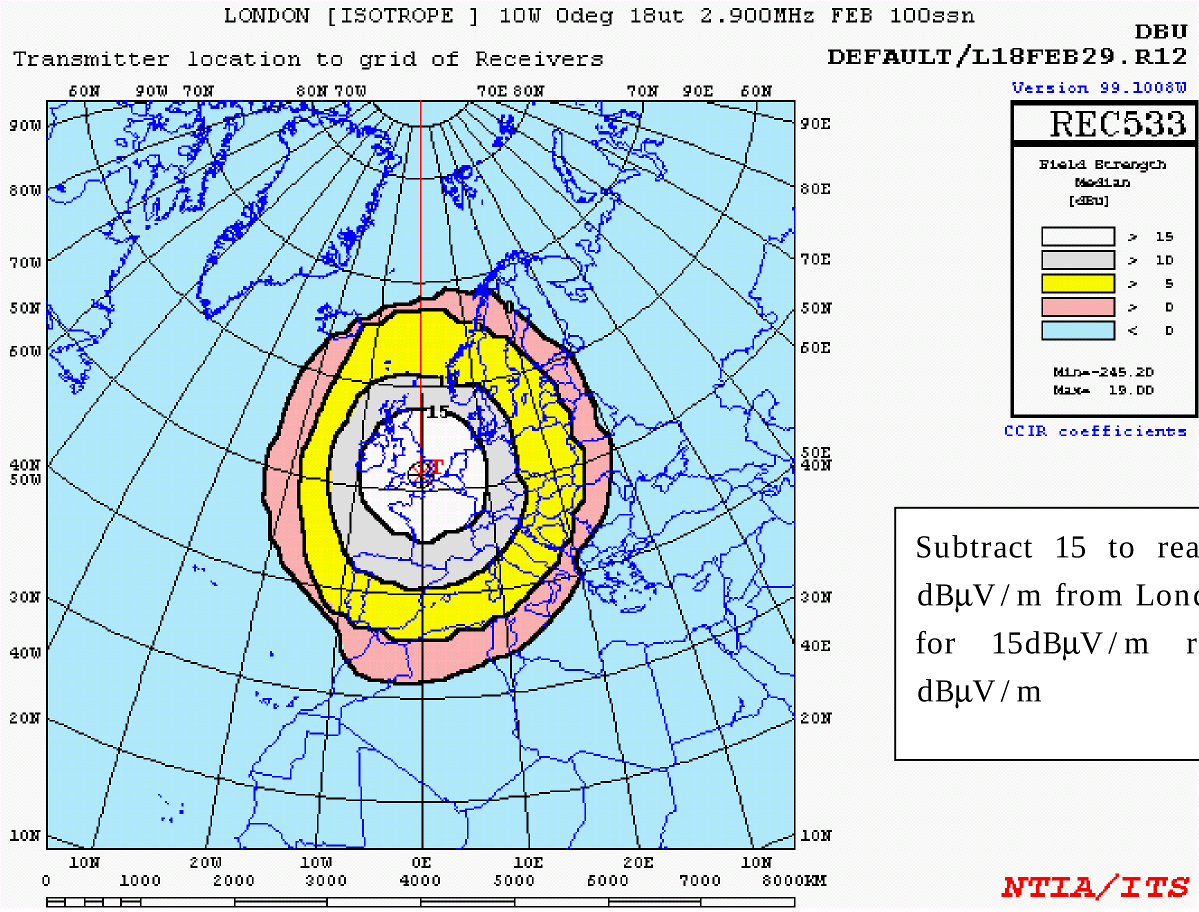
APPENDIX 3 AREA COVERAGE PLOTS OF RADIATION FROM LONDON AT 2.9MHZ AND 5.1MHZ



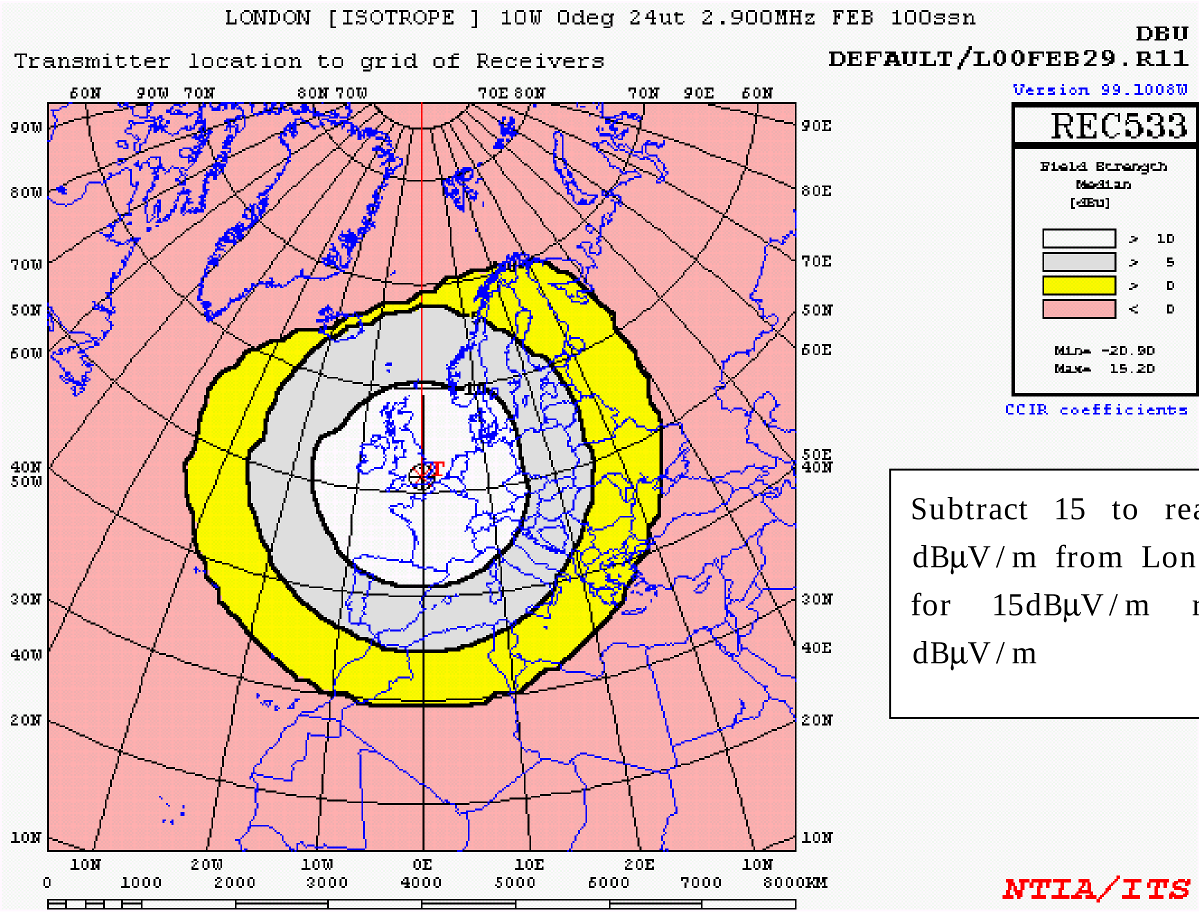
Subtract 15 to read true dBµV/m from London. ie. for 15dBµV/m read 0 dBµV/m



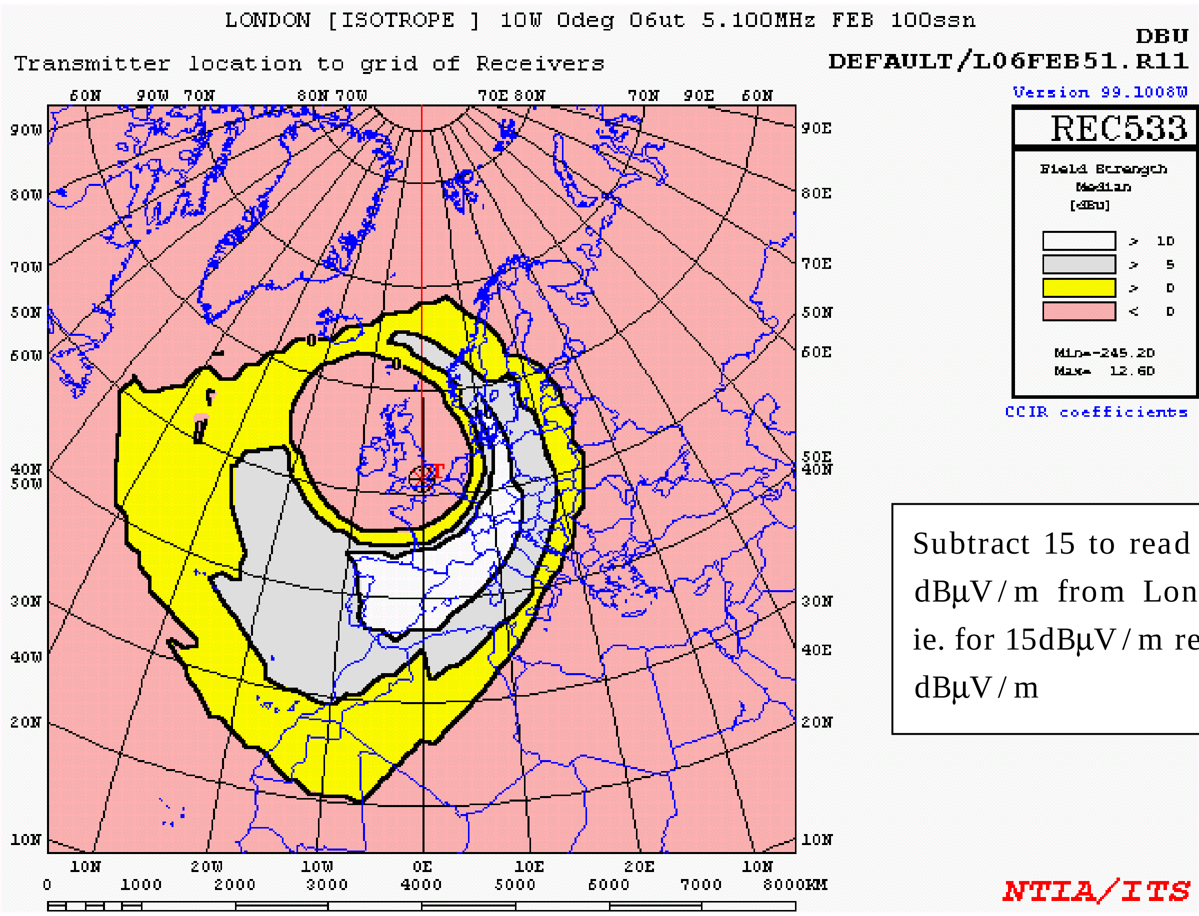
Subtract 15 to read true dBµV/m from London. ie. for 15dBµV/m read 0 dBµV/m



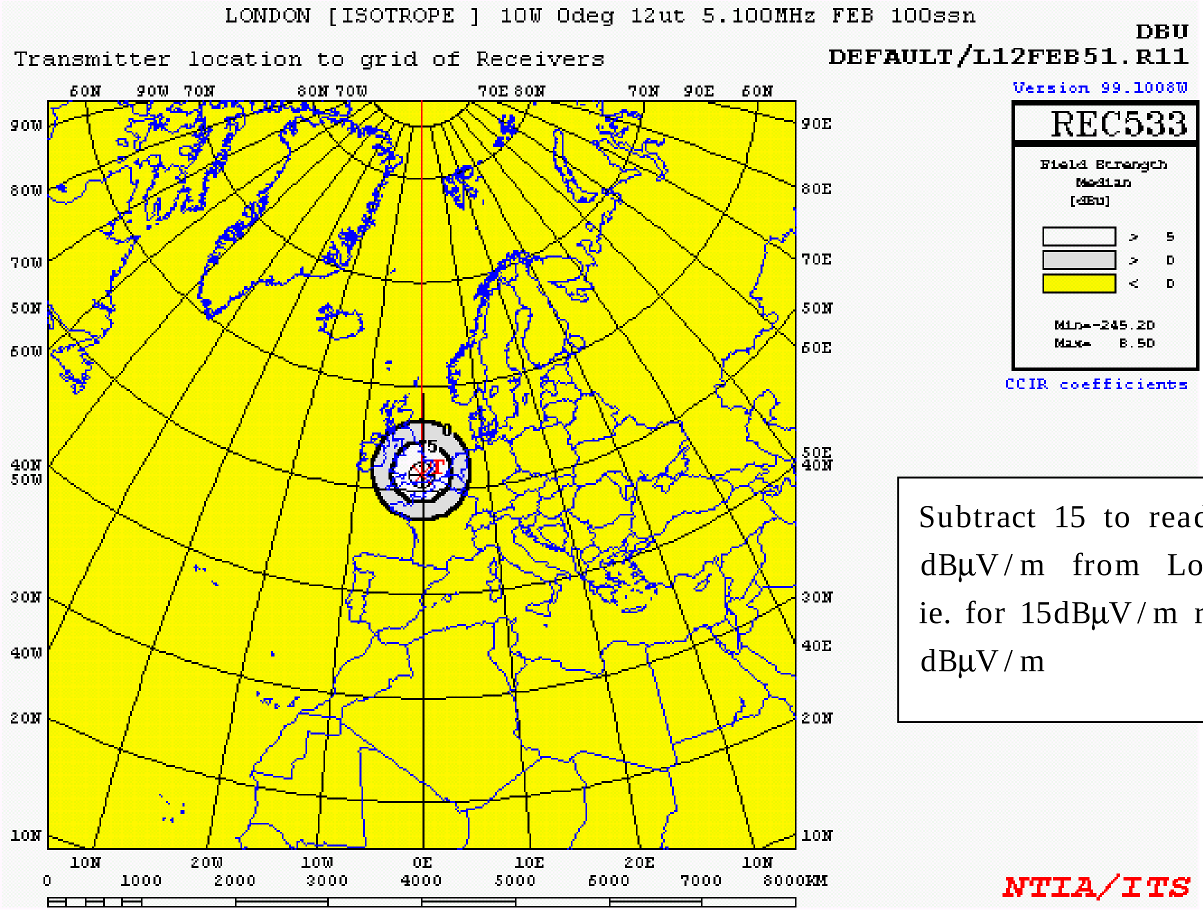
Subtract 15 to read true dBµV/m from London. ie. for 15dBµV/m read 0 dBµV/m



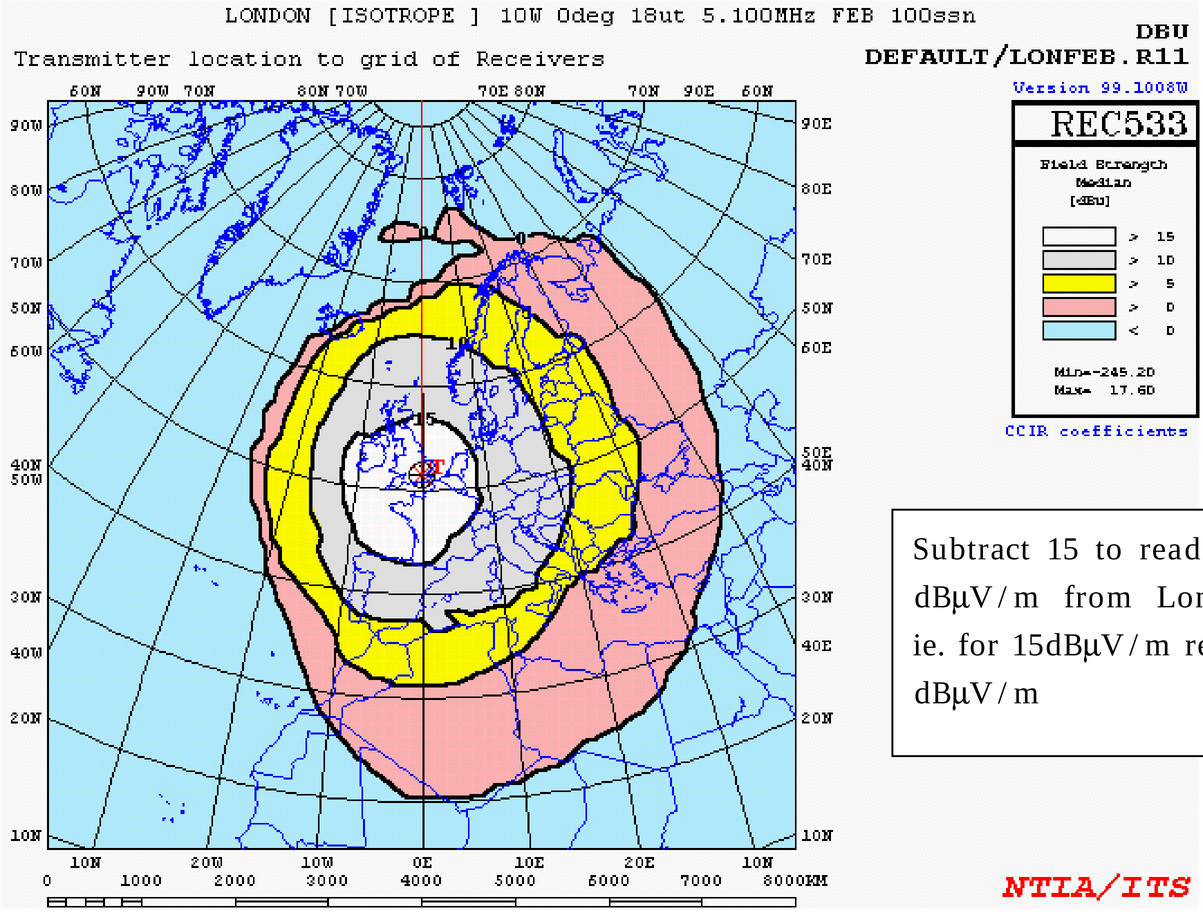
Subtract 15 to read true dBµV/m from London. ie. for 15dBµV/m read 0 dBµV/m



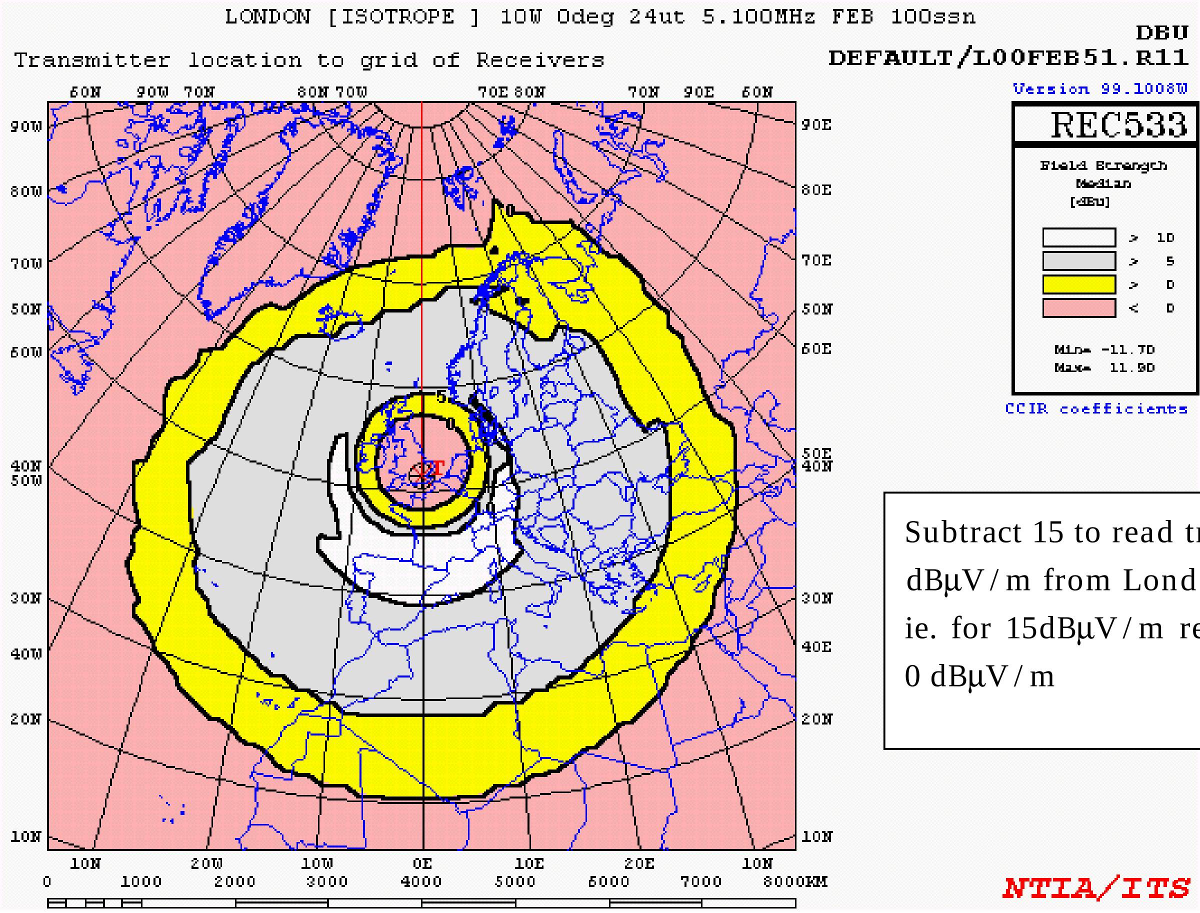
Subtract 15 to read true dBµV/m from London. ie. for 15dBµV/m read 0 dBµV/m



Subtract 15 to read true dBµV/m from London. ie. for 15dBµV/m read 0 dBµV/m

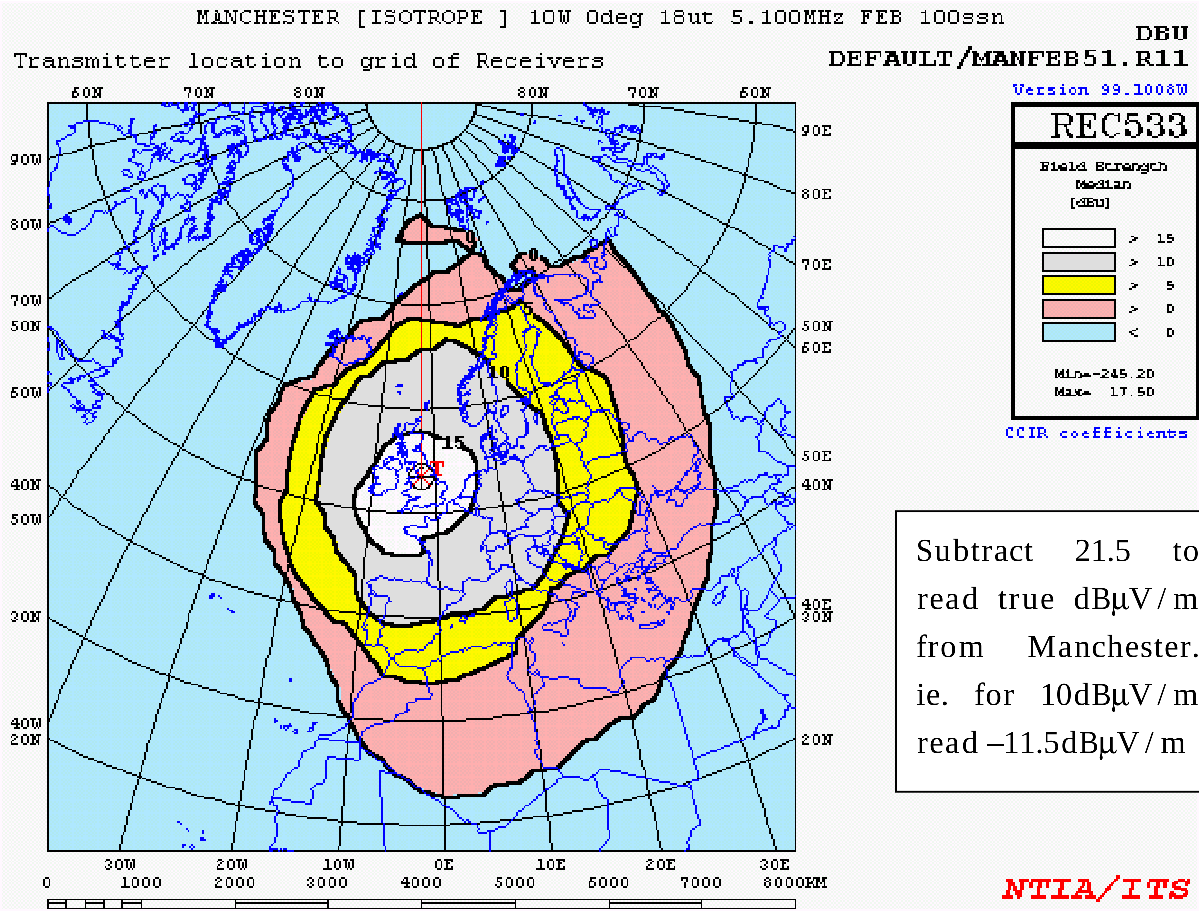


Subtract 15 to read true dBµV/m from London. ie. for 15dBµV/m read 0 dBµV/m

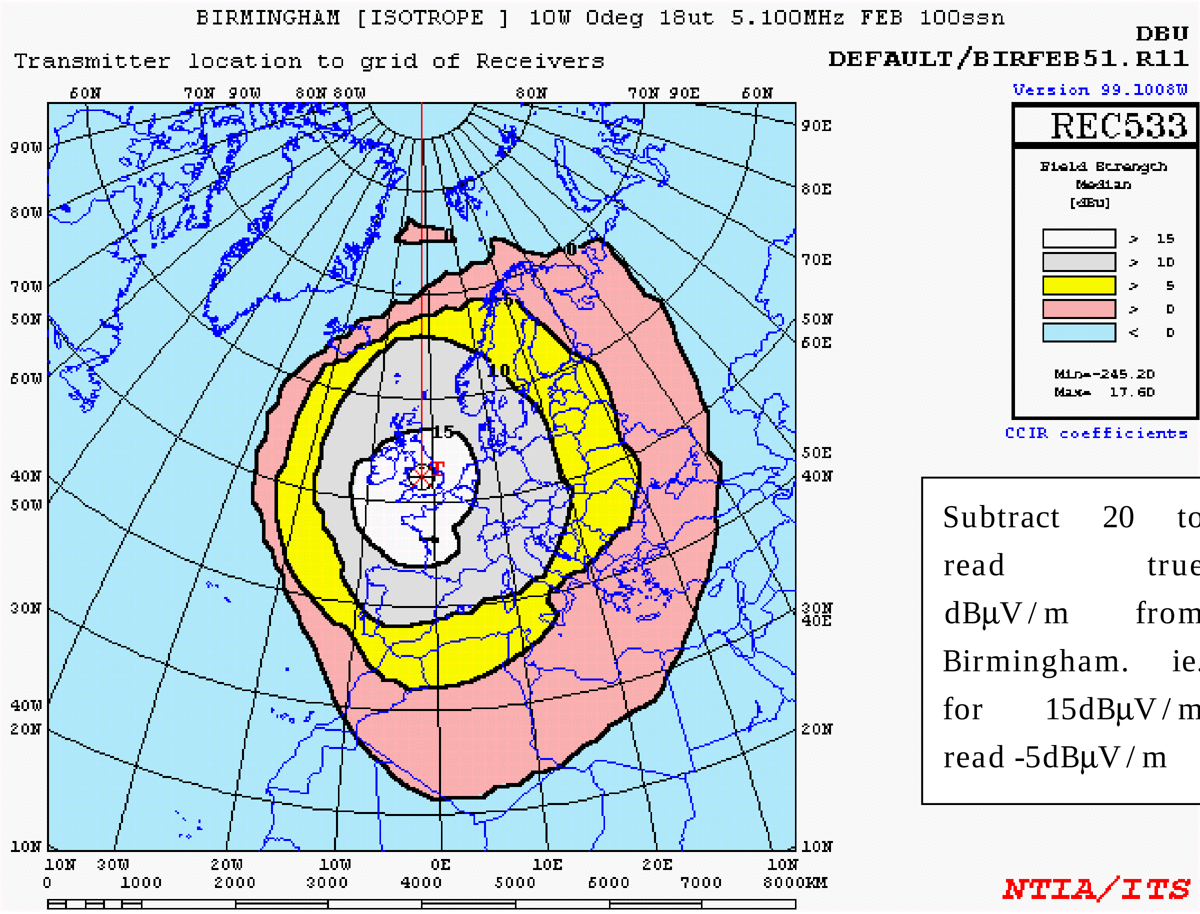


Subtract 15 to read true dBµV/m from London. ie. for 15dBµV/m read 0 dBµV/m

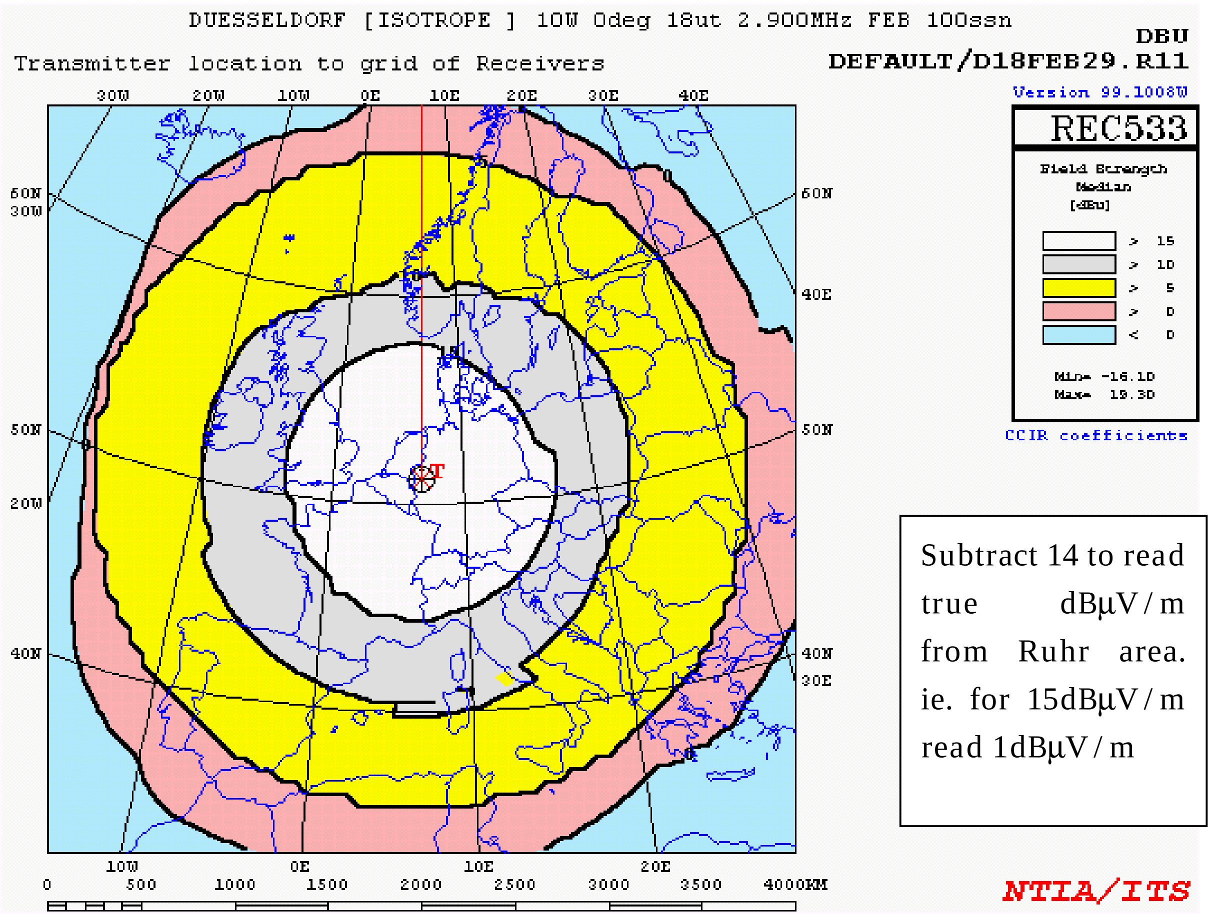
APPENDIX 4 AREA COVERAGE PLOTS OF RADIATION FROM MANCHESTER, BIRMINGHAM AND RUHR INDUSTRIAL AREA OF GERMANY



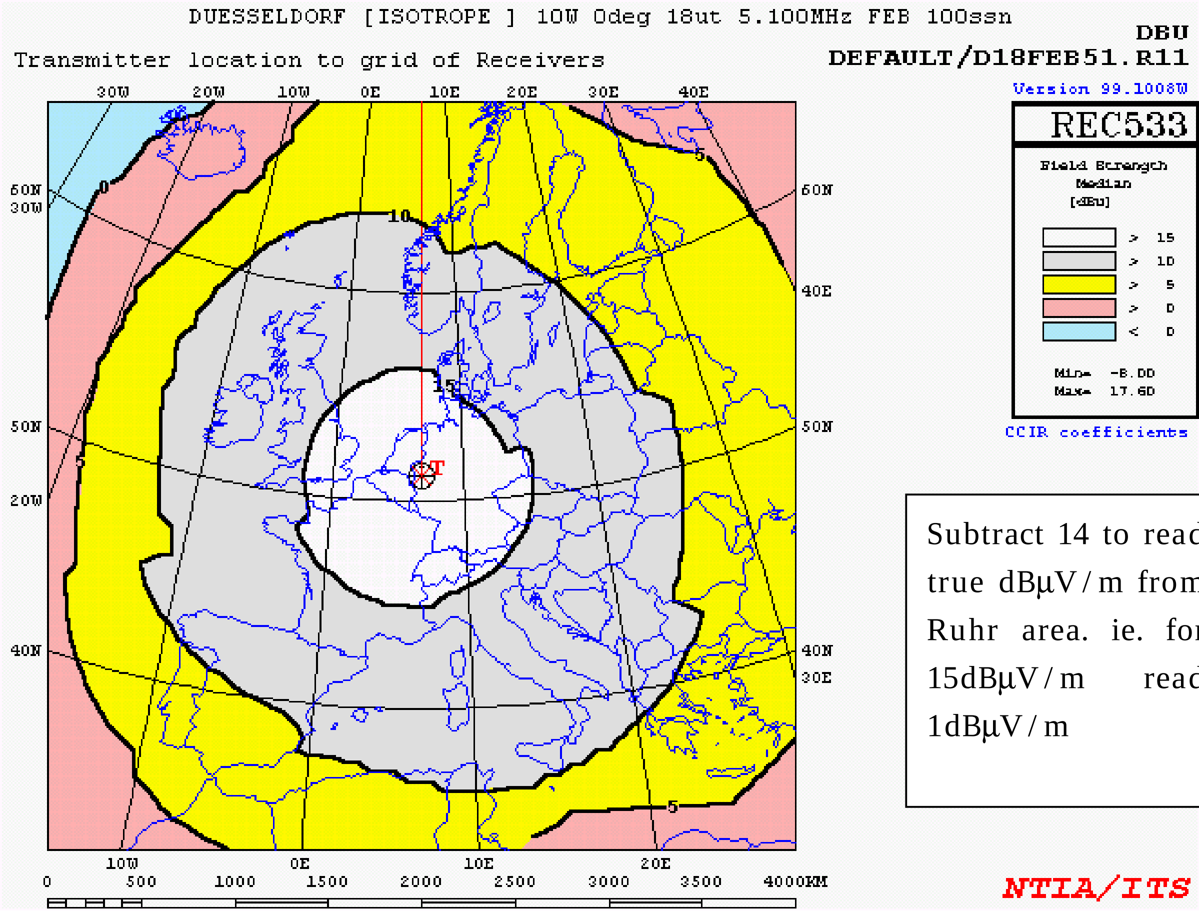
Subtract 21.5 to read true dBµV/m from Manchester. ie. for 10dBµV/m read –11.5dBµV/m



Subtract 20 to read true dBµV/m from Birmingham. ie. for 15dBµV/m read -5dBµV/m



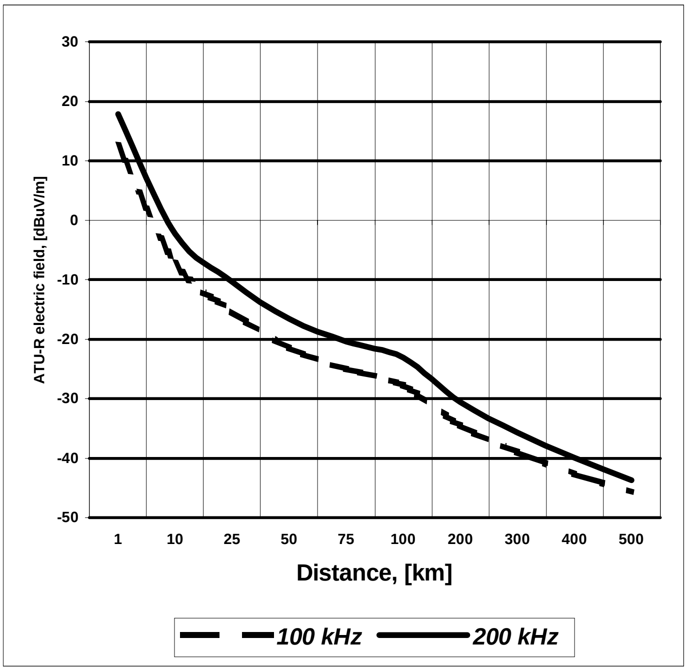
Subtract 14 to read true dBµV/m from Ruhr area. ie. for 15dBµV/m read 1dBµV/m

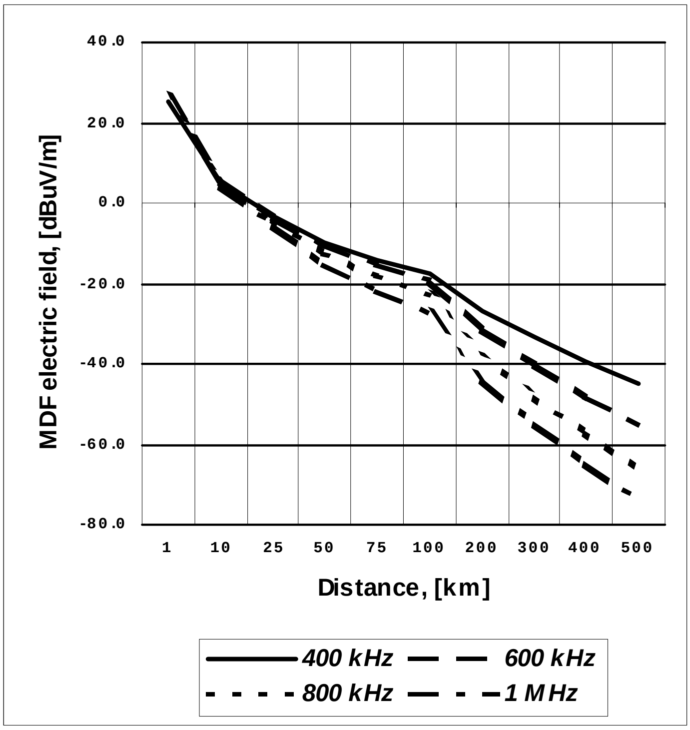


Subtract 14 to read true dBµV/m from Ruhr area. ie. for 15dBµV/m read 1dBµV/m

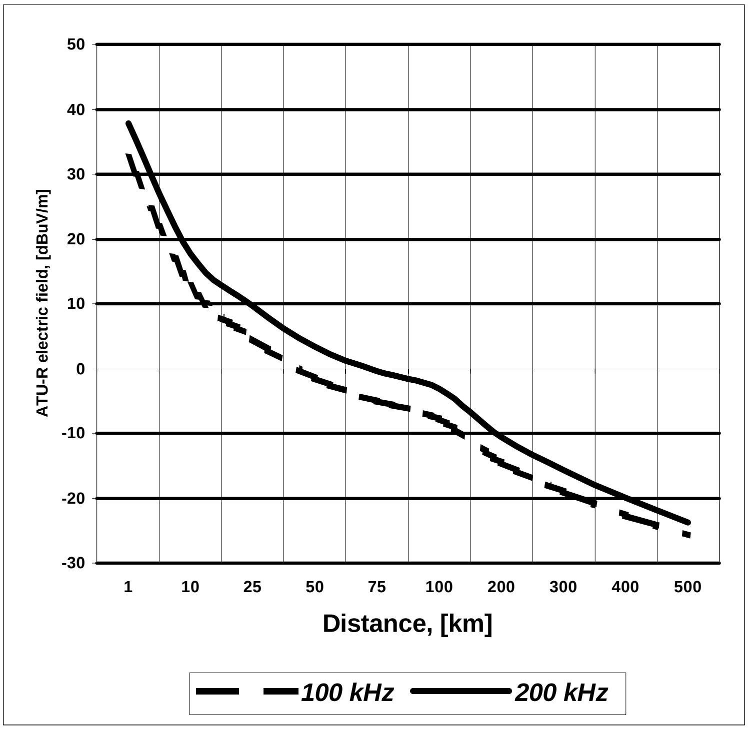
APPENDIX 5 GRAPHS OF CALCULATED ELECTRIC FIELD FOR VARIOUS BALANCE AND MARKET PENETRATION

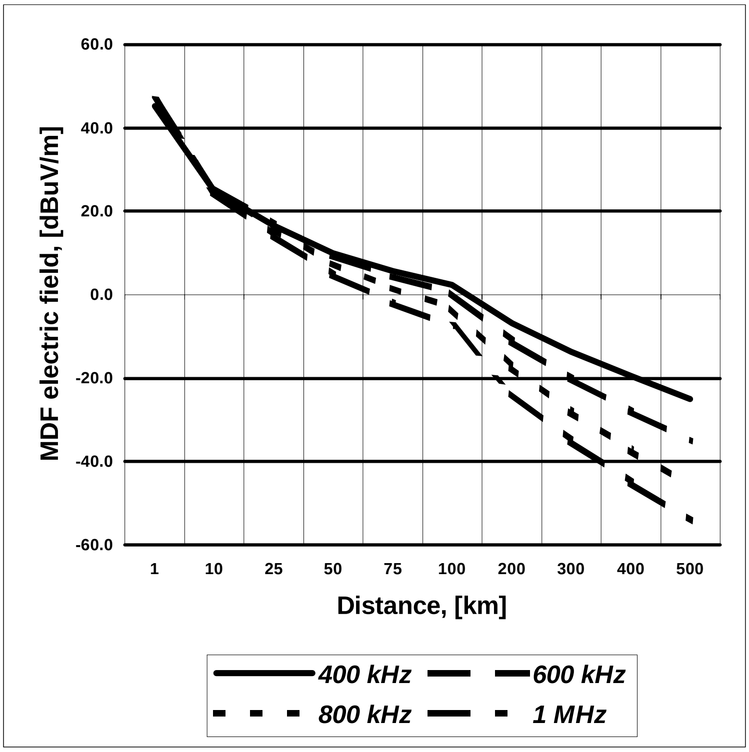
Case 1a. City area *25 km²*, balance *50 dB*, market penetration *20%*, concurrent line usage *30%*.



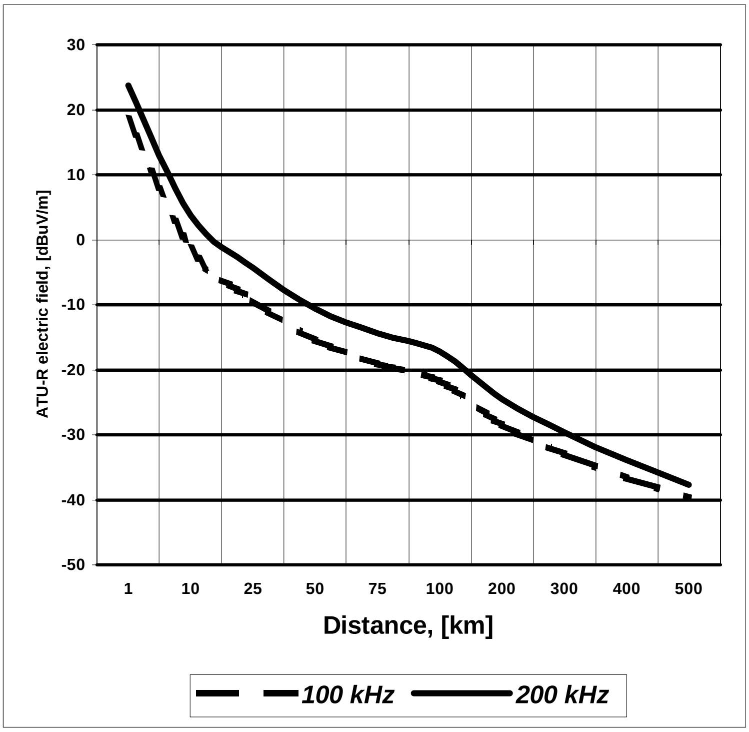


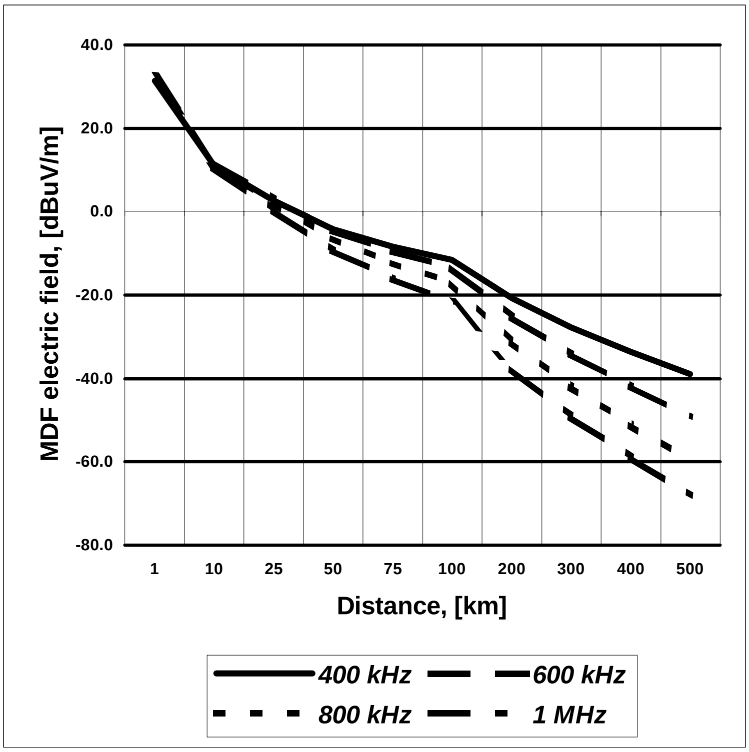
Case 1b. City area *25 km²*, balance *30 dB*, market penetration *20%*, concurrent line usage *30%*.



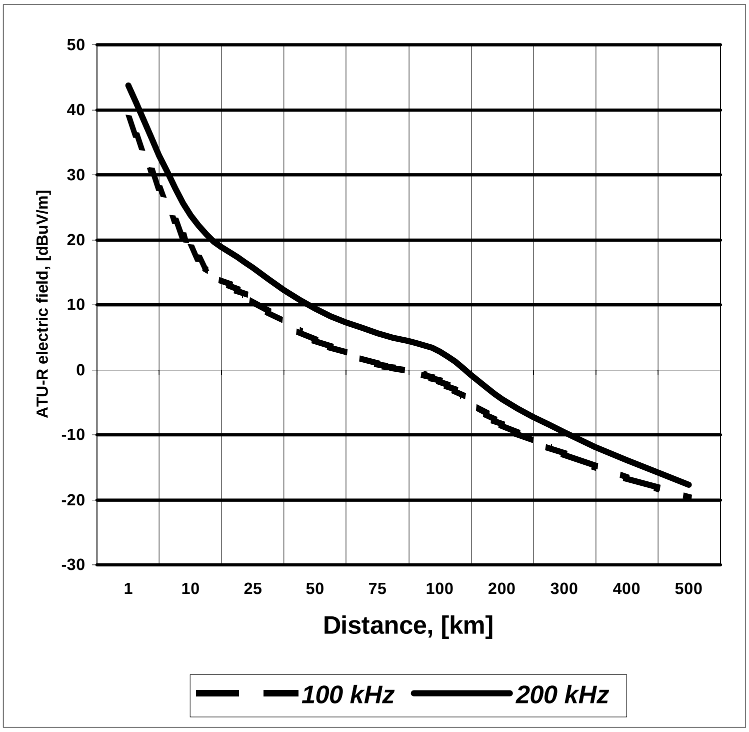


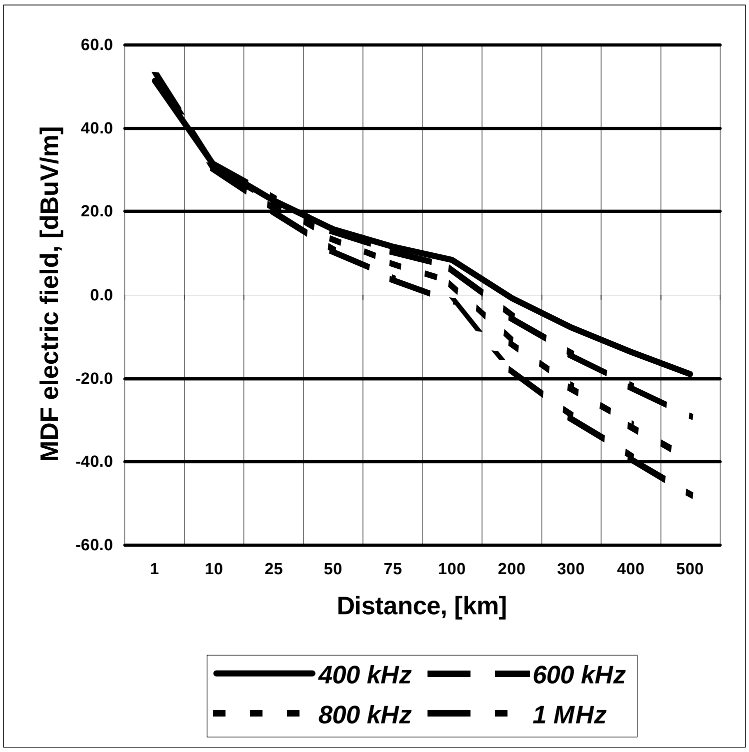
Case 2a. City area *100 km²*, balance *50 dB*, market penetration *20%*, concurrent line usage *30%*.





Case 2b. City area *100 km²*, balance *30 dB*, market penetration *20%*, concurrent line usage *30%*.





APPENDIX 6 TABLES OF CALCULATED ELECTRIC FIELD FOR VARIOUS BALANCE AND MARKET PENETRATION

In this Appendix tabulated results of radiative emissions for the test cases defined in section 6 are given.

Case 1a. City area *25 km²*, balance *50 dB*, market penetration *20%*, concurrent line usage *30%*.

Distance	ATU-R Total Electric Field E(d), [dB µV/m]					
[km]	100 kHz	200 kHz	400 kHz	600 kHz	800 kHz	1 MHz
1	*12.6*	*17.8*	*22.6*	*25.4*	*27.3*	*28.7*
10	*-7.3*	*-2.3*	*2.4*	*4.9*	*6.3*	*7.2*
25	*-15.3*	*-10.4*	*-6.0*	*-4.0*	*-3.2*	*-3.1*
50	*-21.5*	*-16.6*	*-12.7*	*-11.5*	*-11.7*	*-12.8*
75	*-25.1*	*-20.4*	*-17.0*	*-16.5*	*-17.5*	*-19.6*
100	*-27.7*	*-23.2*	*-20.2*	*-20.4*	*-22.3*	*-25.1*
200	*-34.5*	*-30.6*	*-29.4*	*-32.1*	*-36.5*	*-41.1*
300	*-39.0*	*-35.7*	*-36.3*	*-41.1*	*-47.2*	*-52.5*
400	*-42.6*	*-39.9*	*-42.2*	*-48.9*	*-56.3*	*-62.3*
500	*-45.8*	*-43.7*	*-47.7*	*-56.2*	*-64.8*	*-71.6*

Distance	MDF Total Electric Field E(d), [dB µV/m]					
[km]	100 kHz	200 kHz	400 kHz	600 kHz	800 kHz	1 MHz
1	*16.9*	*21.4*	*25.3*	*26.4*	*26.5*	*26.2*
10	*-3.1*	*1.4*	*5.0*	*5.8*	*5.5*	*4.6*
25	*-11.1*	*-6.7*	*-3.4*	*-3.0*	*-4.0*	*-5.7*
50	*-17.2*	*-12.9*	*-10.1*	*-10.5*	*-12.5*	*-15.3*

75	*-20.9*	*-16.7*	*-14.3*	*-15.5*	*-18.3*	*-22.1*
100	*-23.5*	*-19.5*	*-17.6*	*-19.4*	*-23.1*	*-27.6*
200	*-30.3*	*-26.9*	*-26.8*	*-31.1*	*-37.3*	*-43.6*
300	*-34.8*	*-32.0*	*-33.7*	*-40.1*	*-48.0*	*-55.0*
400	*-38.4*	*-36.2*	*-39.6*	*-48.0*	*-57.1*	*-64.9*
500	*-41.5*	*-40.0*	*-45.1*	*-55.2*	*-65.6*	*-74.1*

Case 1b. City area *25* km^2, balance *30 dB*, market penetration *20%*, concurrent line usage *30%*.

Distance	ATU-R Total Electric Field E(d), [dB µV/m]					
[km]	100 kHz	200 kHz	400 kHz	600 kHz	800 kHz	1 MHz
1	*32.6*	*37.8*	*42.6*	*45.4*	*47.3*	*48.7*
10	*12.7*	*17.7*	*22.4*	*24.9*	*26.3*	*27.2*
25	*4.7*	*9.6*	*14.0*	*16.0*	*16.8*	*16.9*
50	*-1.5*	*3.4*	*7.3*	*8.5*	*8.3*	*7.2*
75	*-5.1*	*-0.4*	*3.0*	*3.5*	*2.5*	*0.4*
100	*-7.7*	*-3.2*	*-0.2*	*-0.4*	*-2.3*	*-5.1*
200	*-14.5*	*-10.6*	*-9.4*	*-12.1*	*-16.5*	*-21.1*
300	*-19.0*	*-15.7*	*-16.3*	*-21.1*	*-27.2*	*-32.5*
400	*-22.6*	*-19.9*	*-22.2*	*-28.9*	*-36.3*	*-42.3*
500	*-25.8*	*-23.7*	*-27.7*	*-36.2*	*-44.8*	*-51.6*

Distance	MDF Total Electric Field E(d), [dB μV/m]					
[km]	100 kHz	200 kHz	400 kHz	600 kHz	800 kHz	1 MHz
1	*36.9*	*41.4*	*45.3*	*46.4*	*46.5*	*46.2*
10	*16.9*	*21.4*	*25.0*	*25.8*	*25.5*	*24.6*
25	*8.9*	*13.3*	*16.6*	*17.0*	*16.0*	*14.3*
50	*2.8*	*7.1*	*9.9*	*9.5*	*7.5*	*4.7*
75	*-0.9*	*3.3*	*5.7*	*4.5*	*1.7*	*-2.1*
100	*-3.5*	*0.5*	*2.4*	*0.6*	*-3.1*	*-7.6*
200	*-10.3*	*-6.9*	*-6.8*	*-11.1*	*-17.3*	*-23.6*
300	*-14.8*	*-12.0*	*-13.7*	*-20.1*	*-28.0*	*-35.0*
400	*-18.4*	*-16.2*	*-19.6*	*-28.0*	*-37.1*	*-44.9*
500	*-21.5*	*-20.0*	*-25.1*	*-35.2*	*-45.6*	*-54.1*

Case 2a. City area *100 km²*, balance *50 dB*, market penetration *20%*, concurrent line usage *30%*.

Distance	ATU-R Total Electric Field E(d), [dB μV/m]					
[km]	100 kHz	200 kHz	400 kHz	600 kHz	800 kHz	1 MHz

1	*18.7*	*23.8*	*28.7*	*31.4*	*33.3*	*34.7*
10	*-1.3*	*3.8*	*8.4*	*10.9*	*12.3*	*13.2*
25	*-9.3*	*-4.3*	*0.1*	*2.0*	*2.8*	*2.9*
50	*-15.5*	*-10.6*	*-6.7*	*-5.5*	*-5.7*	*-6.7*
75	*-19.1*	*-14.4*	*-10.9*	*-10.4*	*-11.5*	*-13.5*
100	*-21.7*	*-17.2*	*-14.2*	*-14.4*	*-16.3*	*-19.1*
200	*-28.5*	*-24.6*	*-23.4*	*-26.1*	*-30.5*	*-35.1*
300	*-33.0*	*-29.7*	*-30.3*	*-35.1*	*-41.2*	*-46.5*
400	*-36.6*	*-33.9*	*-36.2*	*-42.9*	*-50.3*	*-56.3*
500	*-39.7*	*-37.7*	*-41.6*	*-50.2*	*-58.8*	*-65.5*

Distance	MDF Total Electric Field E(d), [dB μV/m]					
[km]	100 kHz	200 kHz	400 kHz	600 kHz	800 kHz	1 MHz
1	*22.9*	*27.5*	*31.3*	*32.4*	*32.5*	*32.2*
10	*2.9*	*7.5*	*11.1*	*11.8*	*11.5*	*10.7*
25	*-5.1*	*-0.6*	*2.7*	*3.0*	*2.0*	*0.4*
50	*-11.2*	*-6.9*	*-4.1*	*-4.5*	*-6.4*	*-9.3*
75	*-14.8*	*-10.7*	*-8.3*	*-9.5*	*-12.3*	*-16.1*
100	*-17.5*	*-13.5*	*-11.6*	*-13.4*	*-17.0*	*-21.6*
200	*-24.3*	*-20.9*	*-20.8*	*-25.1*	*-31.3*	*-37.6*
300	*-28.8*	*-26.0*	*-27.6*	*-34.1*	*-42.0*	*-49.0*
400	*-32.4*	*-30.2*	*-33.6*	*-42.0*	*-51.1*	*-58.8*
500	*-35.5*	*-34.0*	*-39.0*	*-49.2*	*-59.5*	*-68.1*

Case 2b. City area *100 km²*, balance *30 dB*, market penetration *20%*, concurrent line usage *30%*.

Distance	ATU-R Total Electric Field E(d), [dB µV/m]					
[km]	100 kHz	200 kHz	400 kHz	600 kHz	800 kHz	1 MHz
1	*38.7*	*43.8*	*48.7*	*51.4*	*53.3*	*54.7*
10	*18.7*	*23.8*	*28.4*	*30.9*	*32.3*	*33.2*
25	*10.7*	*15.7*	*20.1*	*22.0*	*22.8*	*22.9*
50	*4.5*	*9.4*	*13.3*	*14.5*	*14.3*	*13.3*
75	*0.9*	*5.6*	*9.1*	*9.6*	*8.5*	*6.5*
100	*-1.7*	*2.8*	*5.8*	*5.6*	*3.7*	*0.9*
200	*-8.5*	*-4.6*	*-3.4*	*-6.1*	*-10.5*	*-15.1*
300	*-13.0*	*-9.7*	*-10.3*	*-15.1*	*-21.2*	*-26.5*
400	*-16.6*	*-13.9*	*-16.2*	*-22.9*	*-30.3*	*-36.3*
500	*-19.7*	*-17.7*	*-21.6*	*-30.2*	*-38.8*	*-45.5*

Distance	MDF Total Electric Field E(d), [dB µV/m]					
[km]	100 kHz	200 kHz	400 kHz	600 kHz	800 kHz	1 MHz
1	*42.9*	*47.5*	*51.3*	*52.4*	*52.5*	*52.2*
10	*22.9*	*27.5*	*31.1*	*31.8*	*31.5*	*30.7*
25	*14.9*	*19.4*	*22.7*	*23.0*	*22.0*	*20.4*

50	*8.8*	*13.1*	*15.9*	*15.5*	*13.6*	*10.7*
75	*5.2*	*9.3*	*11.7*	*10.5*	*7.7*	*3.9*
100	*2.5*	*6.5*	*8.4*	*6.6*	*3.0*	*-1.6*
200	*-4.3*	*-0.9*	*-0.8*	*-5.1*	*-11.3*	*-17.6*
300	*-8.8*	*-6.0*	*-7.6*	*-14.1*	*-22.0*	*-29.0*
400	*-12.4*	*-10.2*	*-13.6*	*-22.0*	*-31.1*	*-38.8*
500	*-15.5*	*-14.0*	*-19.0*	*-29.2*	*-39.5*	*-48.1*

APPENDIX 7 RESULTS FOR VDSL GROUNDWAVE TEST CASES

Results for case 1a.

Distance	NT-LT Total Electric Field E(d), [dBuV/m]					
[km]	1 MHz	2 MHz	4 MHz	6 MHz	8 MHz	10 MHz
1	*11.44*	*15.17*	*16.72*	*15.78*	*13.66*	*10.07*
10	*-10.10*	-10.45	*-18.61*	*-24.05*	*-27.45*	*-31.26*
25	*-20.39*	-25.66	*-36.32*	*-40.98*	*-44.16*	*-47.90*
50	*-30.02*	-39.74	*-49.64*	*-54.14*	*-57.55*	*-61.28*
75	*-36.82*	-48.18	*-57.79*	*-62.59*	*-66.07*	*-70.13*
100	*-42.37*	-54.34	*-64.14*	*-69.24*	*-72.99*	*-77.28*
200	*-58.35*	-71.35	*-83.17*	*-89.90*	*-95.02*	*-100.49*
300	*-69.76*	-84.60	*-99.17*	*-107.90*	*-114.62*	*-121.47*
400	*-79.59*	-96.85	*-114.46*	*-125.30*	*-133.70*	*-141.96*
500	*-88.82*	-108.74	*-129.47*	*-142.44*	*-152.52*	*-162.19*

Table A7.1a. Electric field strength for upstream transmission for case 1a.

Distance	LT-NT Total Electric Field E(d), [dBuV/m]					
[km]	1 MHz	2 MHz	4 MHz	6 MHz	8 MHz	10 MHz
1	*7.95*	*13.87*	*17.40*	*15.99*	*12.80*	*9.37*
10	*-13.58*	-11.75	*-17.93*	*-23.84*	*-28.31*	*-31.96*
25	*-23.87*	-26.96	*-35.64*	*-40.77*	*-45.02*	*-48.60*
50	*-33.49*	-41.03	*-48.96*	*-53.93*	*-58.41*	*-61.98*
75	*-40.31*	-49.48	*-57.11*	*-62.38*	*-66.93*	*-70.83*
100	*-45.86*	-55.64	*-63.46*	*-69.03*	*-73.85*	*-77.98*

200	*-61.84*	-72.65	*-82.49*	*-89.69*	*-95.88*	*-101.19*
300	*-73.24*	-85.90	*-98.49*	*-107.69*	*-115.48*	*-122.17*
400	*-83.08*	-98.15	*-113.78*	*-125.09*	*-134.56*	*-142.66*
500	*-92.31*	-110.04	*-128.79*	*-142.23*	*-153.38*	*-162.89*

Table A7.1b: Electric field strength for downstream transmission for case 1a.

Results for case 1b.

Distance	NT-LT Total Electric Field E(d), [dB μV/m]					
[km]	1 MHz	2 MHz	4 MHz	6 MHz	8 MHz	10 MHz
1	21.44	25.17	26.72	25.78	23.66	20.07
10	-0.10	-0.45	-8.61	-14.05	-17.45	-21.26
25	-10.39	-15.66	-26.32	-30.98	-34.16	-37.90
50	-20.02	-29.74	-39.64	-44.14	-47.55	-51.28
75	-26.82	-38.18	-47.79	-52.59	-56.07	-60.13
100	-32.37	-44.34	-54.14	-59.24	-62.99	-67.28
200	-48.35	-61.35	-73.17	-79.90	-85.02	-90.49
300	-59.76	-74.60	-89.17	-97.90	-104.62	-111.47
400	-69.59	-86.85	-104.46	-115.30	-123.70	-131.96
500	-78.82	-98.74	-119.47	-132.44	-142.52	-152.19

Table A7.2a: Electric field strength for upstream transmission for case 1b

Distance	LT-NT Total Electric Field E(d), [dB μV/m]					
[km]	1 MHz	2 MHz	4 MHz	6 MHz	8 MHz	10 MHz
1	17.95	23.87	27.40	25.99	22.80	19.37
10	-3.58	-1.75	-7.93	-13.84	-18.31	-21.96
25	-13.87	-16.96	-25.64	-30.77	-35.02	-38.60
50	-23.49	-31.03	-38.96	-43.93	-48.41	-51.98
75	-30.31	-39.48	-47.11	-52.38	-56.93	-60.83
100	-35.86	-45.64	-53.46	-59.03	-63.85	-67.98
200	-51.84	-62.65	-72.49	-79.69	-85.88	-91.19

300	*-63.24*	-75.90	*-88.49*	*-97.69*	*-105.48*	*-112.17*
400	*-73.08*	-88.15	*-103.78*	*-115.09*	*-124.56*	*-132.66*
500	*-82.31*	-100.04	*-118.79*	*-132.23*	*-143.38*	*-152.89*

TableA7.2b: Electric field strength for downstream transmission for case 1b

Results for case 2a.

Distance	NT-LT Total Electric Field E(d), [dB μV/m]					
[km]	1 MHz	2 MHz	4 MHz	6 MHz	8 MHz	10 MHz
1	*17.47*	*21.19*	*22.74*	*21.80*	*19.68*	*16.09*
10	*-4.07*	-4.43	*-12.59*	*-18.03*	*-21.43*	*-25.24*
25	*-14.36*	-19.64	*-30.30*	*-34.96*	*-38.14*	*-41.88*
50	*-23.99*	-33.72	*-43.62*	*-48.12*	*-51.53*	*-55.26*
75	*-30.79*	-42.16	*-51.77*	*-56.57*	*-60.05*	*-64.11*
100	*-36.34*	-48.32	*-58.12*	*-63.22*	*-66.97*	*-71.26*
200	*-52.32*	-65.33	*-77.15*	*-83.88*	*-89.00*	*-94.47*
300	*-63.73*	-78.58	*-93.15*	*-101.88*	*-108.60*	*-115.45*
400	*-73.56*	-90.83	*-108.44*	*-119.28*	*-127.68*	*-135.94*
500	*-82.79*	-102.72	*-123.45*	*-136.42*	*-146.50*	*-156.17*

Table A7.3a: Electric field strength for upstream transmission for case 2a

Distance	LT-NT Total Electric Field E(d), [dB μV/m]					
[km]	1 MHz	2 MHz	4 MHz	6 MHz	8 MHz	10 MHz
1	*13.97*	*19.90*	*23.42*	*22.01*	*18.82*	*15.39*
10	*-7.56*	-5.72	*-11.91*	*-17.82*	*-22.29*	*-25.94*
25	*-17.85*	-20.93	*-29.62*	*-34.75*	*-39.00*	*-42.58*
50	*-27.47*	-35.01	*-42.94*	*-47.91*	*-52.39*	*-55.96*
75	*-34.28*	-43.45	*-51.09*	*-56.36*	*-60.91*	*-64.81*
100	*-39.84*	-49.61	*-57.44*	*-63.01*	*-67.83*	*-71.96*
200	*-55.81*	-66.62	*-76.47*	*-83.67*	*-89.86*	*-95.17*

300	*-67.22*	-79.87	*-92.47*	*-101.67*	*-109.46*	*-116.15*
400	*-77.06*	-92.12	*-107.76*	*-119.07*	*-128.54*	*-136.64*
500	*-86.29*	-104.01	*-122.77*	*-136.21*	*-147.36*	*-156.87*

Table A7.3b: Electric field strength for upstream transmission for case 2a

Results for case 2b.

Distance	NT-LT Total Electric Field E(d), [dB μV/m]					
[km]	1 MHz	2 MHz	4 MHz	6 MHz	8 MHz	10 MHz
1	*27.47*	*31.19*	*32.74*	*31.80*	*29.68*	*26.09*
10	*5.93*	5.57	*-2.59*	*-8.03*	*-11.43*	*-15.24*
25	*-4.36*	-9.64	*-20.30*	*-24.96*	*-28.14*	*-31.88*
50	*-13.99*	-23.72	*-33.62*	*-38.12*	*-41.53*	*-45.26*
75	*-20.79*	-32.16	*-41.77*	*-46.57*	*-50.05*	*-54.11*
100	*-26.34*	-38.32	*-48.12*	*-53.22*	*-56.97*	*-61.26*
200	*-42.32*	-55.33	*-67.15*	*-73.88*	*-79.00*	*-84.47*
300	*-53.73*	-68.58	*-83.15*	*-91.88*	*-98.60*	*-105.45*
400	*-63.56*	-80.83	*-98.44*	*-109.28*	*-117.68*	*-125.94*
500	*-72.79*	-92.72	*-113.45*	*-126.42*	*-136.50*	*-146.17*

Table A7.4a: Electric field strength for upstream transmission for case 2b

Distance	LT-NT Total Electric Field E(d), [dB μV/m]					
[km]	1 MHz	2 MHz	4 MHz	6 MHz	8 MHz	10 MHz
1	*23.97*	*29.90*	*33.42*	*32.01*	*28.82*	*25.39*
10	*2.44*	4.28	*-1.91*	*-7.82*	*-12.29*	*-15.94*
25	*-7.85*	-10.93	*-19.62*	*-24.75*	*-29.00*	*-32.58*
50	*-17.47*	-25.01	*-32.94*	*-37.91*	*-42.39*	*-45.96*
75	*-24.28*	-33.45	*-41.09*	*-46.36*	*-50.91*	*-54.81*
100	*-29.84*	-39.61	*-47.44*	*-53.01*	*-57.83*	*-61.96*
200	*-45.81*	-56.62	*-66.47*	*-73.67*	*-79.86*	*-85.17*

300	*-57.22*	-69.87	*-82.47*	*-91.67*	*-99.46*	*-106.15*
400	*-67.06*	-82.12	*-97.76*	*-109.07*	*-118.54*	*-126.64*
500	*-76.29*	-94.01	*-112.77*	*-126.21*	*-137.36*	*-146.87*

Table A7.4b: Electric field strength for downstream transmission for case 2b

APPENDIX 8 USER MANUAL FOR THE ACTIVE EXCEL SPREADSHEET USED TO CALCULATE CUMULATIVE GROUNDWAVE EMISSIONS FROM THE DEPLOYMENT OF XDSL SERVICES

1. Calculation strategy of cumulative emissions.

In order to calculate the cumulative ground wave interference resulting from the application of the xDSL technology to numerous single users, we need to have knowledge of the physical distribution of the single sources and the manner and geometry of the propagation path by which the interference reaches the victim receiver. Ideally, one would have to consider the particular location of each interference source, determine the propagation from each source to the victim receiver, and perform a power summation. (It can be safely assumed that the signals from the various interference sources are uncorrelated and so their cumulative effect on the receiver can be assessed by power addition, or equivalently by the RSS (Root of the Sum of the Squares) method in terms of the electric field strength). This is however, impractical for widespread systems, and is certainly not possible when the system is yet unrealised and the locations are not known in detail. Instead, one can realistically estimate the density D_i of potential installations, treat the sources as being uniformly spread over a known area and perform the RSS summation method to evaluate the electric field as a function of distance. Thus, the total electric field strength due to m different types of radiating sources is given by

$$E = \sqrt{A\sum_{i=1}^{m} p_i D_i M_{pi} L_i E_i^2}$$

where A is the area in m^2 including all radiating sources, p_i is the percentage of building type associated with the ith radiating source within A, D_i is the density of installations per unit area, M_{pi} is the percentage of market penetration, L_{ui} is the maximum percentage of installed lines used concurrently and E_i is the electric field strength due to the i-type single installation. In the implemented version of the active spreadsheet, seventeen different basic radiating elements associated with common building types found in the UK, including bungalow, semi-detached and detached residential properties, one to ten storey business buildings as well as bundles of cables running from the MDF at the exchange. If the percentage coverage and densities of different types of buildings are known, it is possible to achieve a realistic prediction of the cumulative interference effect.

2. Input model parameters

In order to give the user the flexibility to describe a wide variety of radiative situations, several model parameters can be inputted to the model. Below is a list of the model's input variables.

1. A: the area in km^2 including all radiating sources
2. p_i : the percentage of building type associated with the ith radiating source within A
3. D_i : the density of installations per unit area
4. M_{pi} : the percentage of market penetration
5. L_{ui} : the maximum percentage of installed lines used concurrently

Recent market analysis studies have suggested that new communications technologies, i.e., mobile phones, Internet, etc, tend asymptotically around a 20% market penetration percentage. Thus, it is advised that the user uses a fixed percentage of market penetration of around 20%. The maximum percentage of installed lines used concurrently can be set to values ranging between 5% and 50%, but since usage statistics are not available at present a good suggestion is a value of 30% which is thought to reflect fairly well the usage habits of the xDSL customers (i.e., percentage of customers using xDSL in a Sunday evening).

6. *Rad CF*: The radiation efficiencies quoted in the spreadsheet have been adapted from NEC2 simulations. Although the geometry of each radiative mechanism is thought to be quite close to reality, the results do not actually refer to unshielded twisted pairs but single wire lengths. An adjustment factor has therefore been introduced to bridge any potential future experimentally observed differences from the NEC predicted efficiencies. In view of the absence of hard experimental evidence at present, this parameter has been set to 0 dB. Once experimental data become available the radiation correction factor may be adjusted or discontinued accordingly.
7. *Att*: The transmitted signal will suffer attenuation since it is travelling along a lossy transmission line. The attenuation per unit length of the line is frequency dependent and the user may enter his/her own parameters if they are available for a certain system. The current values used in the spreadsheet have been adapted from Figure 10 of

Czajkowski's paper [1]. The user has to enter his/her own value for the length of the cable (field I31).

8. *Bal*: One of the most important system parameters linked directly to the radiative emission field and near-end (NEXT) as well as far-end (FEXT) cross-talk interference. Consideration of the balance of access cables is of paramount importance, as it is directly related to both ingress and egress issues. The current values of balance used in the spreadsheet have been suggested by Figure 10 of Czajkowski's paper [1].

9. *PSD*: The transmit spectral masks for the various derivatives of xDSL are defined in the appropriate ETSI and/or ANSI standards. The values inserted in the relevant fields of the spreadsheets have been adapted from standards ETSI TS101-388 (11-1998) [2] and ETSI TS101-270-1 (10-1999) [3].

10. *Cpl*: For the ADSL scenario and especially for the downstream transmission case where great numbers of UTPs are grouped in bundles (bundles originating from the MDF centre may contain a few thousand cables) a coupling input model parameter has been introduced. Preliminary calculations using NEC, suggested that the presence of several pairs in the same bundle decreases the radiation efficiency of an individual pair. This results to a reduction of the overall radiation efficiency. The so called "coupling loss" is expected to be frequency dependent and this is reflected by the values inserted -albeit arbitrarily due to lack of hard experimental evidence- in the appropriate column.

<u>All input field headings have been marked in red colour so that the user can instantly recognise which parameters can be subject to change.</u>

3. Results

Once the input model parameters have been set, the spreadsheet proceeds to calculate for downstream and upstream transmissions:

a) *the unattenuated electric field for each radiative element,*

b) *the appropriate electric field correction factor,*

c) *the total interference electric field by performing the summation described in section 1.*

The final results are tabulated in page 2 of the spreadsheet both in tabular and graphical form. The presentation of cumulative emission results is straightforward and can be compared directly with the established radio noise floor values shown in both tabular and graphical form. The user may wish at this point to develop the spreadsheet further, by generating tables of differences between the established radio noise values and the calculated emission field values at fixed distances. Subsequently, the effect of widespread application of xDSL technologies on existing and future radio services can be readily evaluated.

4. Epilogue

An active spreadsheet has been developed which allows the rapid calculation of likely cumulative emissions from the widespread application of xDSL technologies. Provided correct values for the input parameters are selected, the field predictions are expected to be in reasonably good agreement with experimentally reported data. Although, the conceptual design of the model is thought to represent quite accurately the physical mechanisms giving rise to cumulative emissions, the model output is quite sensitive to the selection of input parameters. It is thus strongly advised that:

1. Realistic data of city building makeup are surveyed and subsequently fed as input parameters to the model.
2. Extensive measurements of the cable balance of existing metallic distribution access networks are made to determine the true average value of cable balance.
3. The radiative characteristics of typical UTP wiring configurations associated with the xDSL technology are rigorously assessed by experimental measurements and that the theoretically derived NEC results used in the spreadsheet are accordingly amended.
4. The radiative characteristics of long overhead distribution runs of unshielded twisted pairs are rigorously assessed and built into the model at a later stage.

5. Useful reference documents

[1]. Czajkowski, I K, "High-speed copper access: a tutorial overview", Electronics & Communication Engineering Journal, June 1999, pp. 125-148.

[2]. ETSI Technical Specification TS 101 388 V1.1.1 (1998-11), [ANSI T1.413 - 1998, modified], "Transmission and Multiplexing (TM); Access transmission systems on metallic access cables; Asymmetric Digital Subscriber Line (ADSL) - Coexistence of ADSL and ISDN-BA on the same pair".

[3]. ETSI Technical Specification TS 101 270-1 V1.2.1 (1999-10), "Transmission and Multiplexing (TM); Access transmission systems on metallic access cables; Very high speed Digital Subscriber Line (VDSL) - Part 1: Functional requirements", European Telecommunications Standards Institute 1999.

[4]. Papatsoris, A D, Flinthoft, I D, and Welsh, D W, "Groundwave propagation of cumulative emissions from ADSL systems", Technical report R99/271, deliverable 2 part 2 (AY 3525) for Radiocommunications Agency, York EMC Services, January 2000.

[5]. Welsh, D W, Papatsoris, A D, Flinthoft, I D, "Groundwave propagation of cumulative emissions from VDSL systems", Technical report R99/272, deliverable 2 part 2 (AY 3525) for Radiocommunications Agency, York EMC Services, February 2000.